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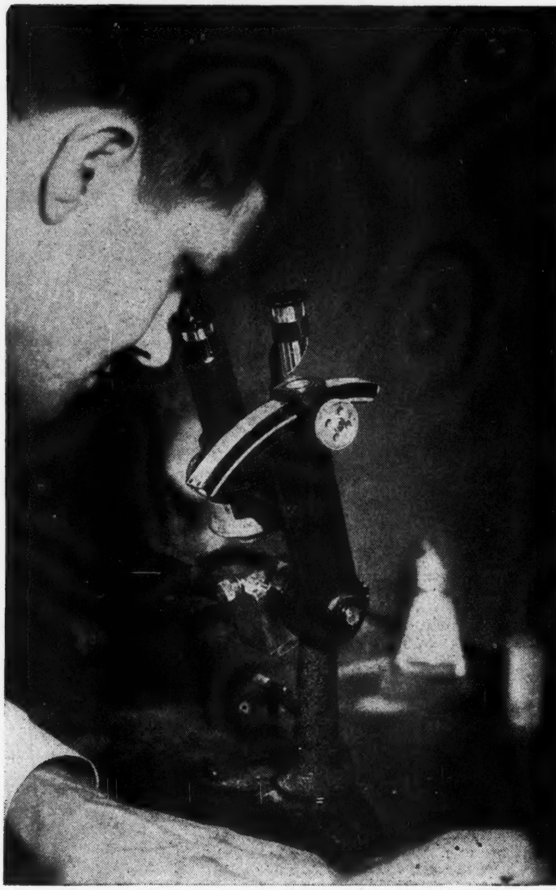

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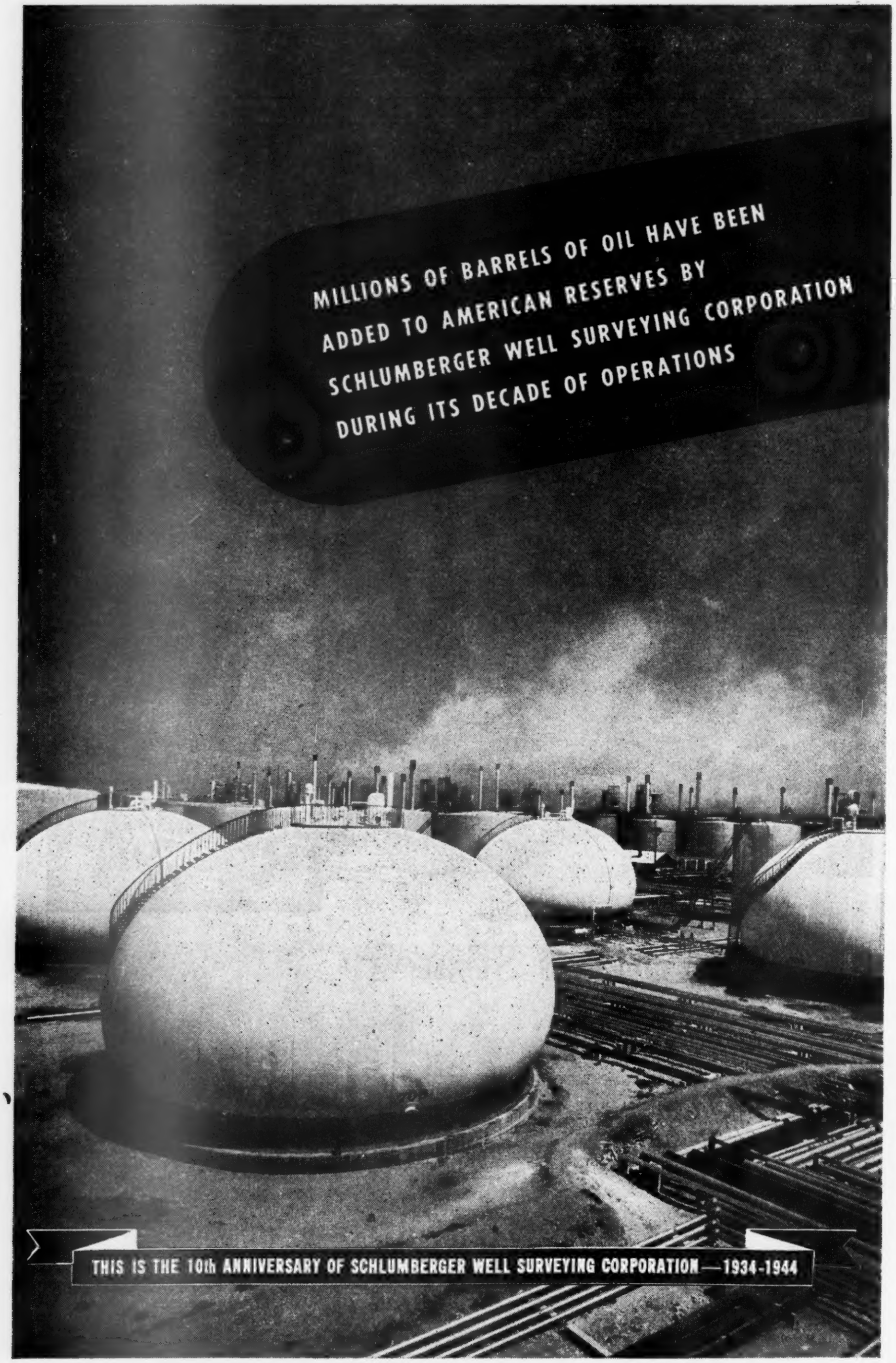
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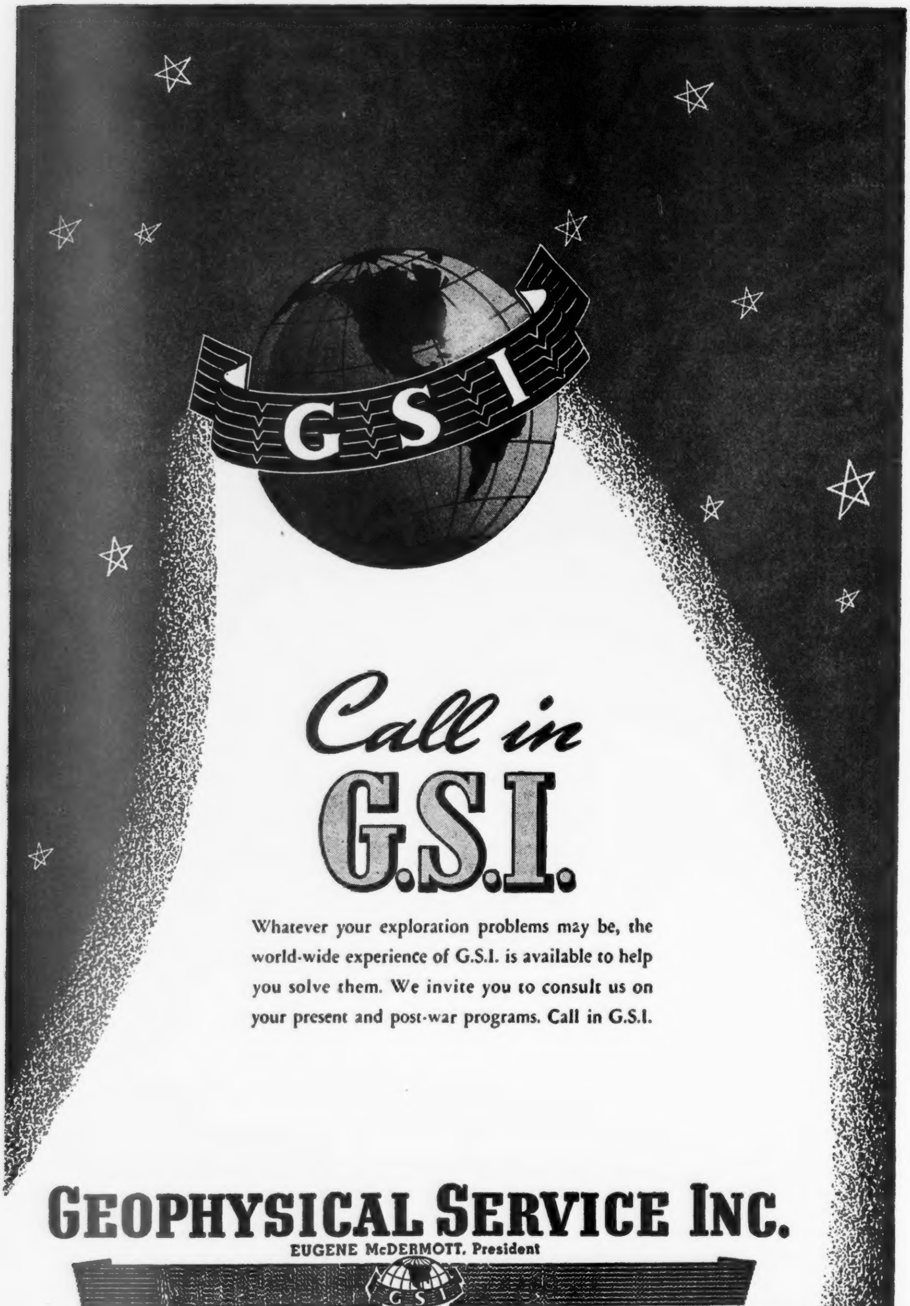
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OCTOBER, 1944

OUTLINE OF CHINESE GEOLOGY[1]

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ABSTRACT

The structural framework of Greater China consists of three positive areas and the geosynclines that separate and enclose them. These are compared with analogous features of eastern North America.

A thick succession of Paleozoic formations accumulated in a great trough which extended northeast and southwest across China proper. At the end of Ordovician time this trough was restricted on the north and Silurian, Devonian and Mississippian strata are unrepresented in north China. The Pennsylvanian and Permian seas, however, again extended into that area.

Eastern Asia was uplifted at the end of Triassic time and subsequent sedimentation was almost entirely non-marine. Mountain-forming movements, which began in mid-Pennsylvanian time and have continued with modifications to the present, produced a series of shifting sedimentary basins in which all later formations accumulated.

The structure of central Asia is dominated by curving east-west mountain arcs but the coastal region is characterized by northeast-southwest trending structures. Throughout much of China proper these two systems have produced a complicated interference pattern.

Diastrophism that affected central and eastern Asia since the Paleozoic era was so profound that most parts of China are intensely folded and faulted. Five large sedimentary basins are present, however, two in Chinese Turkistan, one in Tibet, and two in western and northern China proper.

INTRODUCTION

As compared with North America or Europe, the geology of Asia is little known. One of its largest subdivisions, China, with an area half as large again as the United States, has come under investigation by her own people only during the last generation. Chinese geologists are few in number but they have studied many areas and have brought to light much information extending and bringing up to date the observations of foreign explorers, for example, Richthofen, Obrutchov, Willis, and Blackwelder, whose work provides the foundation on which Chinese geology stands. However, large parts of Chinese central Asia, particularly in Tibet, Sinkiang, and Mongolia are as little known to-day as almost any place on earth.

Except for studies in a few mostly small and scattered areas, practically all geological investigations in China, by Chinese and foreigners alike, have been of the reconnaissance type and almost no detailed mapping, such as we are accus-

[1] Read before the Association at Dallas, March 23, 1944. Manuscript received, May 12, 1944. The material presented here is largely abstracted and adapted from the works listed in the appended bibliography.

[2] Illinois State Geological Survey.

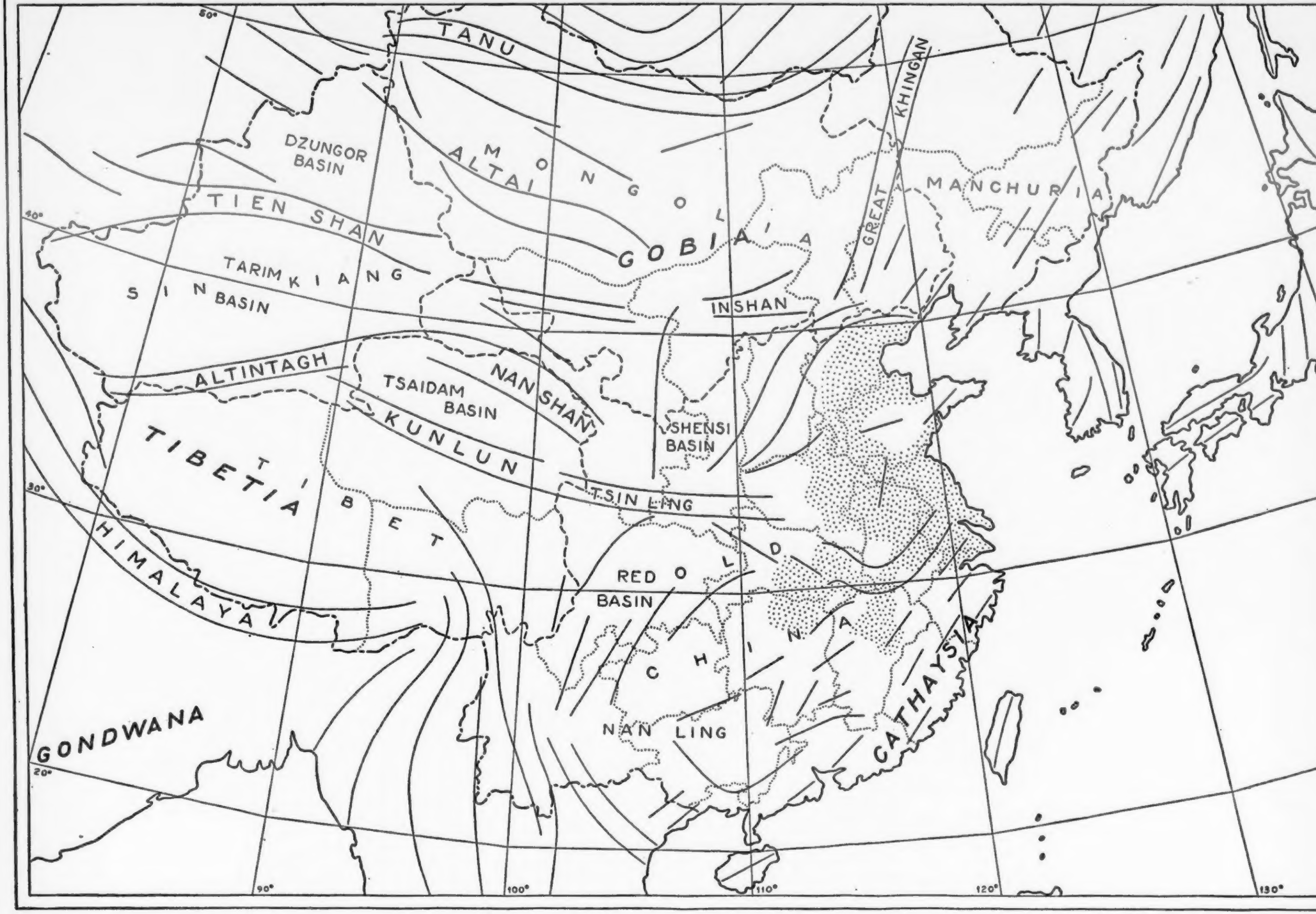

FIG. 1.—Tectonic map of Greater China showing ancient positive landmasses, directions of structural trends, locations of principal mountain ranges, and positions of larger basins. Modern alluvial basins are stippled.

tomed to in this country, has been done. In consequence the major features of Chinese stratigraphy and geologic history are fairly clear but many important details remain to be discovered. Numerous recognized formations are very thick, their correlations are approximate, and doubtless significant unconformities have been overlooked. Refinements along these lines must await much additional painstaking field work and paleontological study.

STRUCTURAL FRAMEWORK

The basic structural elements of China may be compared with similar features in eastern North America. These consist of three positive areas and three geosynclines. The first positive area is Cathaysia, an ancient landmass which, like Appalachia, extended northeast and southwest along the continental border. In former times it probably extended to or beyond the arcs of islands that festoon the Asiatic coast. Like Appalachia it was an important barrier and source of sediments throughout Paleozoic time.

Although the geology of Tibet is practically unknown, a second positive area, Tibetia, is believed to be enclosed between the ranges of the Himalaya and Kunlun mountains. The existence of this area is not entirely theoretical because it is plainly indicated by many structural and stratigraphic facts. Although it is relatively much more important, Tibetia may be compared with the Ozark region of the Mississippi valley. Southwest of Tibetia and beyond the limits of China lies the ancient landmass and positive area of Gondwana which finds its North American parallel in Llanoria.

The third positive area of China is Gobia in Mongolia which, to continue the American analogy, may be likened to Laurentia in Canada. From a continental standpoint, however, Gobia is a much less dominating feature and is separated by a geosyncline from Angara in Siberia which is more nearly similar to the ancient positive region of eastern Canada.

Cathaysia is separated from Tibetia and Gobia by the Cathaysian geosyncline which corresponds with the Paleozoic terrane of the United States east of the Mississippi river. This great trough extends northeast and southwest and in it accumulated a very thick succession of Paleozoic formations. It was never a simple syncline and is now broken by at least two pronounced axes of uplift which are comparable with the Cincinnati anticline but are much more complicated structurally. Both extend north-northeast and south-southwest. The first is plainly evidenced by the Liaotung Peninsula of southern Manchuria and the Shantung Peninsula of northeastern China. The second begins with the Great Khingan Mountains on the border between Manchuria and Mongolia, passes through Shansi province, intersects the eastern tip of Szechuan and continues into Kweichow province. Between Cathaysia and the first axis lie the modern alluvial basins of Kiangsu and Kiangsi provinces. Between the two axes lie the great Manchurian lowlands and the modern alluvial basins of Hopei-Honan and Hupei-Hunan provinces. West of the second axis lie the Mesozoic Shensi basin and the Red basin of Szechuan.

The two other geosynclines extended along either side of Tibetia and constituted the northern and southern branches of the Asiatic Tethys. The Himalayan geosyncline separating Tibetia from Gondwana is much the better known and may be compared with the Ouachita trough of Arkansas and eastern Oklahoma; it contains sediments representative of every system from the Sinian to the Eocene.

The Nan Shan[3] geosyncline between Tibetia and Gobia may have been equally important during the Paleozoic era but comparatively little is known about the sediments which it contains. It is roughly comparable with the Forest City basin of Missouri and Iowa.

STRATIGRAPHIC HISTORY

Pre-Cambrian.—The pre-Cambrian rocks of China are exposed at many places and are separated into three systems that bear similar relations to each other as do the Kewatin, Huronian, and Keweenawan of North America. The Taishan system, the oldest, consists of a very complex assemblage of gneiss, schist, highly metamorphosed sediments, and igneous intrusions. The overlying Wutai system is made up of metamorphic rocks that are obviously sedimentary in origin. At the end of the Wutai period intense diastrophism was widespread and a long interval of erosion followed so that the youngest, or Sinian, system appears to have been deposited in the depressions of a warped peneplaned surface. The Himalayan, Cathaysian, and Nan Shan geosynclines probably originated at this time. The Sinian rocks are mainly sedimentary beginning with arkosic clastics below and passing upward into enormous bodies of more or less cherty limestone containing obscure algal bodies as its only fossils. It also contains economically important sedimentary iron ores, a widespread tillite, and local extrusive basic lavas. The Sinian system achieves its maximum known development along the Hopei-Jehol boundary where the lower clastic part is about 5,000 feet and the overlying limestone more than 3,000 feet thick.[4] Dynamic metamorphism of the Sinian beds is slight or non-existent except where they have been involved in much later mountain-forming deformation.

Cambrian.—Cambrian strata succeed the Sinian without notable discordance and at several places no unconformity is evident. Early Cambrian submergence probably reached China by way of the Himalayan geosyncline. The sea expanded far northeastward in the Cathaysian geosyncline and also spread laterally and Lower Cambrian strata locally overlap the Sinian and rest on the older crystalline rocks. The strata are mainly clastic although some limestone is present and many layers are abundantly fossiliferous. The Lower Cambrian may attain a maximum thickness of 1,000 or more feet in northern Hopei province and in central Yunnan.

[3] The meanings of the Chinese words *shan* and *ling* are mountain or mountains and range, respectively.

[4] Figures quoted here and on succeeding pages generally represent maximum thicknesses. At other places corresponding strata may be much thinner and they are entirely absent in some areas.

In mid-Cambrian time the sea withdrew from the southern part of the Cathaysian geosyncline but later it readvanced southward and Upper Cambrian strata locally overlap upon the Sinian. Limestone becomes a much more important constituent of the middle and upper parts of the system. Some of the Middle Cambrian beds are conspicuously oölitic and limestone conglomerate is characteristic of some of the Upper Cambrian. Middle Cambrian strata reach a thickness of 1,000–1,500 feet in south Manchuria and neighboring areas and Upper Cambrian strata are locally as much as 500 feet thick.

The Lower Cambrian has not been recognized in the Nan Shan geosyncline but Middle and Upper Cambrian strata have been identified in the eastern part of the Tien Shan.

Ordovician.—No important deformative movement separated the Cambrian and Ordovician periods and Lower Ordovician strata, mainly limestone, dolomite, and graptolite-bearing shale to a thickness of 2,000 feet and possibly more than 5,000 feet succeed the Cambrian without discordance. At the beginning of this period the sea seems to have receded from south China but it soon spread back into the southern part of the Cathaysian geosyncline and continued into the Himalayan trough.

A widespread unconformity separates Lower and Middle Ordovician beds. The younger strata, also mainly limestone, occur in much the same areas as the Lower Ordovician but faunas on the north and south are remarkably different and the Cathaysian geosyncline is believed to have been interrupted by a land barrier at about the position of the Tsin Ling axis so that Upper Ordovician strata accumulated in two separate basins. These beds are 1,500–2,000 feet thick in the north but rarely more than 300 feet thick in south China.

Massive limestone lithologically similar to the Ordovician occurs in the Nan Shan geosyncline and strata of this age are definitely known to be present in the eastern Tien Shan.

In late Ordovician time broad earth movements resulted in the uplifting of north China and Gobia and this region, including the northern part of the Cathaysian geosyncline north of the Tsin Ling axis was not again submerged until Upper Carboniferous time.

Silurian.—Silurian beds succeed Ordovician in central and south China unconformably but without structural discordance. As the north rose at the end of the Ordovician period the sea spread widely over the south. The Silurian sea, however, was generally shallow and the strata that accumulated within it are mainly graptolite-bearing shales with subordinate amounts of limestone and sandstone exceeding 3,000 feet in thickness. The deepest part of this sea seems to have existed in part of the Tsin Ling area where more than 2,000 feet of Silurian limestone is present. Youngest Silurian beds are known only in Yunnan province where they consist of 1,200 feet of thin-bedded limestone and shale.

The Chinese Silurian is connected with beds of similar age in the Himalayan geosyncline and Silurian strata have also been recognized in the Nan Shan geosyncline and in the western Tien Shan.

Caledonian disturbance.—Caledonian orogeny was not particularly important in China as a whole but in the region of the Nan Ling younger strata succeed the Silurian with angular unconformity at several places and mountains were formed in the southwest. This was the first time that local folding, as contrasted with broad warping, occurred in China since pre-Sinian time.

Devonian.—At the beginning of the Devonian period all of China was land undergoing more or less severe erosion. Lower Devonian deposits where present in the south are mostly non-marine clastics and locally they are plant-bearing. They attain a maximum thickness of about 10,000 feet south of the western Tsin Ling but elsewhere rarely exceed 600 feet.

In Middle Devonian time the sea re-entered the interior of China from the Himalayan geosyncline laying down first transgressive sandstones and shales and later limestones. Then occurred a temporary and partial withdrawal evidenced by the recurrence of barren sandstone at several localities. Limestone was again deposited in Upper Devonian time except at the borders of the expanded sea. Middle Devonian sediments attained a thickness of about 1,500 feet. The barren sandstones reach a maximum of about 500 feet and Upper Devonian strata are locally 1,500–2,000 feet thick.

On the whole, the Devonian period in China was a time of fluctuating shallow seas. Cathaysia existed as a sediment-producing land area. The Nan Shan geosyncline was flooded in late Devonian time. Rocks of this age are recorded in the Kunlun, Tien Shan, and Altai ranges.

Liukiang disturbance.—At the close of the Devonian period Cathaysia appears to have subsided and there was folding in Kiangsi province, and perhaps elsewhere, so that locally Devonian and Lower Carboniferous formations are separated by an angular unconformity.

Mississippian.—The early Mississippian sea advanced into the Cathaysian geosyncline and spread eastward onto the peneplaned slope of Cathaysia. Limestone with variable amounts of clastic sediments accumulated to a thickness of 1,200 feet in southwestern China, thinning toward the north. This sea contracted in mid-Mississippian time and sandstone with coaly shale 300 feet thick locally formed in the south. A great re-advance of the sea occurred in late Mississippian time and shaly limestone to a maximum thickness of more than 1,000 feet was widely deposited in China and the Nan Shan geosyncline.

Lower Pennsylvanian.—Broad earth movements occurred in eastern Asia at the close of the Mississippian period. Lower Pennsylvanian (Moscovian) beds succeed the Upper Mississippian (Visean) unconformably but without notable discordance. However, the Pennsylvanian was much more widely distributed and extends into north China and beyond where it overlies undisturbed Ordovician strata. The Lower Pennsylvanian is mainly limestone in south and central China and reaches a maximum thickness of 2,000 or more feet. Northward it passes into a thinner coal-bearing series with subordinate limestone members.

Kunming disturbance.—In middle or late Pennsylvanian time intense orogenic

movements involving folding and overthrusting began in Indo China and extended to a lesser degree into southwestern China. This was probably the time when deformation of the Nan Shan geosyncline likewise began. Elsewhere in China only gentle warping prevailed.

Upper Pennsylvanian.—Upper Pennsylvanian (Uralian) strata succeed lower beds without angular discordance throughout most of China but in both the north and central parts of the country they overlap onto older formations. In central and south China these beds are mainly limestone up to 600 feet thick but some coal is present in several districts. Northward coal deposits become more important and deposition in north China obviously fluctuated repeatedly between marine and continental conditions. In places strata of this type nearly 1,000 feet thick accumulated.

Lower Permian.—The Lower Permian succeeds the Upper Pennsylvanian without discordance and bituminous limestone locally attaining a thickness of more than 1,000 feet was widely deposited throughout central and southwestern China. The earliest Permian beds of north China are marine but soon fluctuations of the sea occurred and continental strata, including coals, were formed which rapidly increased in relative importance. This series extended into the shrunken Nan Shan geosyncline and probably achieved a maximum thickness of more than 2,000 feet.

Tungwu disturbance.—Early Permian sedimentation was terminated by renewed orogenic diastrophism which was particularly important in the Nan Shan geosyncline, where the Kunlun Mountains were uplifted, folded and faulted, and which extended with diminishing intensity southward and eastward well across the Cathaysian geosyncline. Vulcanism was active in southwestern China where Lower Permian limestone is succeeded by lava flows. North China however, was little affected. This disturbance marked the climax of the Appalachian revolution in eastern Asia.

Middle and Upper Permian.—The Tungwu disturbance produced many basins of variable size in southern China and in them accumulated coal-bearing, mostly continental clastic sediments with subordinate marine limestone members. These beds locally attain a thickness of more than 1,500 feet and at some places are separated from the Lower Permian by an angular unconformity. Most of the important coal fields of south China are of this age. North China stood above sea level but part of Mongolia was temporarily submerged.

The Upper Permian generally consists of interstratified marine limestones, sandstones and plant-bearing shales reaching a thickness of 3,500 feet in Kweichow province. In northwestern China and some other parts of central Asia the Middle and Upper Permian is non-marine and consists of 3,000–4,000 feet of clastic sediment, with conspicuous redbeds and conglomerates produced by the erosion of newly formed mountains.

Triassic.—Triassic sediments succeed the Upper Permian in central and southwestern China and there are areas where these systems appear to be con-

formable. Clastic beds 500 or more feet thick pass upward into marine limestone that is petroliferous and includes beds of rock salt. This limestone attains a maximum thickness of 2,000 feet and extends into the eastern Nan Shan region but is unknown farther west. The mid-Triassic sea did not encroach upon Cathaysia. Upper Triassic beds where present in south China are mostly non-marine and locally include thin coals. Triassic or "Permo-Triassic" strata of northern China and central Asia consist of a continental redbed succession of characteristic purplish color at least 3,000 feet thick that may continue the Upper Permian without interruption.

Post-Triassic disturbance.—At or near the close of Triassic time eastern Asia was uplifted and China was never again subjected to extensive or prolonged marine submergence. Intense folding occurred in Indo China and more moderate folding has been recognized in east-central China. Elsewhere varying amounts of readjustment occurred because strata of the Jurassic period overlie rocks of many different ages.

Jurassic.—Jurassic beds, wherever they occur, are continental clastics which evidently accumulated in many more or less isolated basins. In general they are coal-bearing below and pass upward, particularly in the north, into redbeds. Thicknesses vary up to a possible maximum of 3,000 or more feet.

Ningchin disturbance.—The Jurassic period was closed by folding and thrust faulting that was particularly intense along the Tsin Ling axis although both in the Shensi basin at the north and in the Red basin at the south a stratigraphic break between the Jurassic and Cretaceous is not evident. Similar movements took place along other mountain axes in northern China and beyond and less intense movements have been recognized in south China.

Cretaceous.—In northwestern and west-central China the oldest strata probably Cretaceous in age include widespread fresh- or brackish-water limestone and black shale. Otherwise this system is represented by continental clastics with conspicuous redbeds and locally gypsum in the upper part. These sediments accumulated to a thickness of as much as 12,000 feet in various basins that did not correspond entirely with the older Jurassic basins and they overlap onto many different rocks including the pre-Cambrian crystalline rocks. Marine Cretaceous is known only in western Sin Kiang province.

Yenshan disturbance.—In middle and late Cretaceous time violent volcanic activity occurred in numerous areas and apparently continued until the end of the period. Lava poured out in large flows principally in the Great Khingan and southeast upland regions. Many acid intrusions were injected into the older rocks to be followed later by smaller intrusions of basic type. Associated hydrothermal activity resulted in the development of a variety of metalliferous veins and contact metamorphic deposits. Folding and faulting of considerable importance likewise occurred.

Early Tertiary.—Continental Tertiary redbeds are widely distributed in

China, especially in the north and in other parts of central Asia. They occupy many basins of different size that do not entirely correspond with the older Cretaceous basins. In general the sedimentary basins of the Permian and later systems appear to have become progressively smaller and more numerous as new mountainous ridges were thrust upward, until in Tertiary time many of the older ridges were partly or completely buried. Early Tertiary strata have not been accurately dated at many places but are known to contain Eocene and Oligocene beds and they may continue into the Miocene. They probably attain a combined maximum thickness of at least 15,000 feet. They overlie a great variety of older formations and include local lignite, gypsum, fresh-water limestone, and interbedded lava flows. Marine Eocene is known in the western part of the Tarim basin but apparently this sea did not continue much farther eastward.

Maoshan disturbance.—The Himalayan geosyncline was intensely folded and raised into mountains in late Eocene time and further uplift occurred at later intervals.

In mid-Tertiary time faulting and some folding occurred in China particularly in the north and in Mongolia. This was followed by erosion and the development of a peneplain that is remarkably well preserved in large areas of central Asia. Later the peneplain was warped and extensively block-faulted.

Late Tertiary.—The youngest Tertiary strata consist of more or less unconsolidated redbeds whose thickness may approach a maximum of 1,500 feet. They are Pliocene in age and are commonly nearly horizontal or only gently inclined except along the flanks of some of the mountain ranges.

Recent disturbance and deposits.—Still younger deposits of piedmont gravels of Pleistocene and Recent age, locally of great thickness, likewise have been warped and faulted along the mountain fronts and it is quite evident that the highland areas of central Asia continue to rise at the present time. Evidence of recent uplift is also furnished by the profound dissection of the loess plateaus of north China and the deep entrenchment of many Chinese rivers. In contrast, recent depression of parts of central and northeastern China, and the coastal region generally, is indicated by the great alluvial plains of the Yellow and Yangtse rivers, the irregularity of the southeastern coast line and the fact that fresh-water shells have been recovered in borings from depths of as much as 500 feet below sea-level as at Tientsin.

STRUCTURE

The coastal region of China is characterized by northeast-trending structures that parallel the elongation of the ancient landmass of Cathaysia and the complementary Cathaysian geosyncline. In contrast, central Asia is dominated by mountain structures extending east and west in curving arcs. The Cathaysian trend is conspicuously developed throughout the greater part of China proper and Manchuria but the eastward continuation of certain central Asiatic structures into

the Cathaysian geosynclinal region has produced much interference, local irregularity, and cross folding.

The most prominent east-west zone is that of the Kunlun and Tsin Ling mountains which extends without interruption into central China halfway across the Cathaysian geosyncline. Still farther the influence of this axis is plainly indicated by structures that do not conform with the Cathaysian trend. Similar but less pronounced zones of cross folding occur at the north where the In Shan appears to be the eastern representative of the Tien Shan and also at the south where the irregular and confusing structures of the Nan Ling region may be related to the Himalayan axis.

Both the Cathaysian and central Asiatic trends are of very ancient origin and probably reflect the fundamental continental framework. Both trends are obviously the result of powerful compressive forces and their relations suggest that northern and central Asia was thrust southward against the diagonal flank of the relatively resistant Cathaysia with resulting pronounced shearing in the Cathaysian geosynclinal zone.

Although the Paleozoic history of greater China was remarkably similar in many ways to that of eastern North America, subsequent deformation in Asia has been so great that the present geologic conditions are quite different. China as a whole is a land of mountains and mountain structure and there are few places from which mountainous ridges can not be seen on a clear day. Sharp folding and great faults are the rule and few large areas of moderate structural deformation still exist.

Deformation of the Asiatic region from earliest time through the Paleozoic era resulted principally in folding and associated thrust faulting, and mountains formed in the Nan Shan geosyncline near the close of that era were of the folded type. During later disturbances in the Nan Shan, Kunlun, and other regions on the north, however, folding progressively declined and was replaced in importance by block faulting. By Tertiary time block faulting dominated to the exclusion of folding except at the borders of depressed basin areas, and most of the present mountains of central Asia owe their existence to block faulting even though they may be composed of rocks intensely folded at some previous time.

Close folding of the rocks in a zone of weakness appears to result in increased strength to compressive stress. Consequently, thrusting from the north, which had previously found relief in the folding of the Nan Shan geosyncline, was, in Tertiary time, largely transmitted to the south, and folded mountains were raised in the Himalayan geosyncline which had not previously suffered important deformation.

In several regions of more intense disturbance Sinian and Paleozoic rocks have suffered from dynamic metamorphism and likewise in some areas even younger strata have been altered. Also contact metamorphism has occurred particularly near intrusions of late Cretaceous age.

SEDIMENTARY BASINS

Sedimentary basins in China were largely co-extensive with the geosynclinal troughs until near the close of the Paleozoic era. Subsequently a succession of violent mountain-forming disturbances destroyed the continuity of the geosynclines, greater China was raised above the sea, and later sedimentation was concentrated in a series of inter-mountain basins. From time to time these basins shifted as depressions were filled and dividing ridges were buried or worn away by erosion and as new mountains were uplifted. At the present time there are five large basins and innumerable smaller ones, containing comparatively undisturbed Tertiary and older sediments as well as the modern alluvial basins of northeastern China and the lower Yangtse valley. The five large basins are the Dzungor and Tarim basins of Sinkiang, the Tsaidam basin of Chinghai, the Shensi basin of north Shensi and eastern Kansu and the Red basin of Szechuan province.

Dzungor basin.—The Dzungor basin is enclosed between the Tien Shan and Altai mountains in northern Sinkiang province. It is a comparatively little known region and its exploration has been conducted almost exclusively by Russian geologists whose reports, published in the Russian language, are unintelligible to most investigators of other nationalities. Dzungaria, however, appears to offer oil possibilities of considerable promise and important seepages have been reported to occur as follows:

Near T'a-cheng (Chugachak) about	47° N., 83° E.
Near Sui-tin (near Kulja) about	44° N., 81° E.
Near Wu-su (Ussu) about	44°30′ N., 85° E.
Near T'i-hua (Urumchi) about	44° N., 87°30′ E.

Tarim basin.—The Tarim basin lies south of the Tien Shan and north of the Altintagh and Kunlun mountains in southern Sinkiang province. It is occupied by the Taklamakan desert, one of the most desolate and absolutely barren parts of the earth's surface. This is a great area of shifting dunes of sand and silt entirely without water and almost totally lacking in animal and vegetable life. Various Paleozoic marine formations ranging in age from Cambrian to Permian have been recognized at a few places in the mountains that enclose it and marine strata of Cretaceous and Eocene ages almost certainly extend into the basin region from the west. Mesozoic and Tertiary continental formations are also well represented on its borders. Geologic conditions within the basin, however, are totally unknown and the suggestion has been offered that it is underlain by a resistant tectonic block which intervened between the Nan Shan trough and a possibly separate Tien Shan geosyncline. An oil seepage has recently been discovered on its northern border.

Tsaidam basin.—The Tsaidam basin of northeastern Tibet is enclosed between the Nan Shan and Kunlun ranges. It is a region without exterior drainage standing at an average elevation of about 10,000 feet. Aside from the facts that it encloses a large marshy area of drab silt and is bordered in places by Tertiary

redbeds, its geology is unknown. Native travellers report an oil seepage on its southern border.

Shensi basin.—The Shensi basin includes parts of northern Shensi and eastern Kansu provinces and extends northward into Inner Mongolia. It is enclosed between a series of low mountains on the west and the flank of the great Shansi arch on the east and extends north and south between the In Shan and Tsin Ling zones of east-west mountain folding. Seepages early attracted attention to the oil possibilities of this region and Japanese, American, and Chinese efforts at development successively failed in attaining important results.

The geological features of the Shensi basin are well known. It lies within the limits of the Cathaysian geosyncline and contains a thick series of formations of Ordovician, Upper Carboniferous, Permian, Mesozoic, and Tertiary ages. It lies within the heart of the great loess region of China but outcrops are abundant along the deeply incised valleys.

Strata within the basin are raised into a series of marginal folds, parallel with the mountain structures on the east and south, which, in a distance of 25 or 30 miles, decrease in magnitude and pass into a monocline dipping toward the center of the basin at the rate of 50 feet per mile. This dip appears to continue nearly to the western boundary of the basin.

Seepages are reported to issue from beds of the Triassic and Jurassic system which are non-marine in origin in this region. About 40 wells have been drilled at various times since 1907. Most of them were very shallow and the deepest was about 3,000 feet. Showings were encountered in several and one well produced about 50 barrels per day for a short time in 1929 from a depth of about 500 feet.

Red basin.—The Red basin lies south of the Tsin Ling zone and occupies the central part of Szechuan province. It contains a thick section of non-marine Mesozoic, and possibly Tertiary beds, overlying marine Triassic limestone. It occurs within the limits of the Cathaysian geosyncline but the nature of the Paleozoic succession beneath the basin is not known.

Strata in the southern part of the Red basin are raised into a series of anticlinal folds generally trending northeast and southwest. Most of them are asymmetrical and compression of the structures increases from west to east.

Oil seepages occur on or near anticlinal structures at several places and numerous showings have been encountered elsewhere in wells drilled for brine. Gas under low pressure likewise occurs. This basin is considered more fully in the following article.

Smaller Tertiary basins.—Small basins containing Tertiary redbeds are numerous in northern and northwestern China proper and other parts of central Asia. Geologic conditions in some of these basins are evidently favorable for oil production and the only producing field in China is in a basin of this type in northwest Kansu province.

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PETROLEUM POSSIBILITIES OF RED BASIN OF SZECHUAN PROVINCE, CHINA[1]

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ABSTRACT

The Red basin of Szechuan province contains a thick series of Mesozoic and possibly Tertiary redbeds which overlies Triassic marine limestone and a largely unknown succession of Paleozoic formations. Many anticlinal folds are known, and oil is present in small amounts at several seepages and in numerous wells drilled for brine. Prospects for production from the redbeds do not appear to be good. The Triassic limestone does not contain oil in commercial quantities on one well formed anticline, but it has been tested at only one other locality. Possibilities of the underlying Paleozoic beds, particularly the Permian which probably occurs throughout the basin, are worthy of careful consideration.

INTRODUCTION

Oil seepages have been known for many years in Sinkiang, Kansu, and Shensi provinces of northwestern China, and recently seepages have been reported in eastern and central Chinghai province. In 1939 a small pool was opened in northwestern Kansu by the National Oil Administration of the Chinese Government which has a current potential producing capacity of about 5,000 barrels per day. Exploration and development in Sinkiang was briefly undertaken by the Russians and is now being continued by the Chinese. Small quantities of oil have likewise been found at seepages and in the brine wells of Szechuan province and in Carboniferous geodes and Triassic limestone of Kweichow province in the western and southwestern part of China proper. Of all these areas, Szechuan province appears to be most interesting, both because of the general structural and stratigraphic nature of the Red basin and because this densely populated province, whose industrial importance has vastly increased since the beginning of the war, will undoubtedly constitute a large local market if oil should be produced.

RED BASIN

Much of central Szechuan province is a structural and topographic basin 400 miles long and more than 200 miles wide which contains a thick succession of non-marine Mesozoic and Tertiary sediments whose prevailing brilliant color has provided the region with its very appropriate name. This basin is surrounded by more or less lofty mountains formed by the upthrusting of older and more resistant rocks. It is drained by the navigable Yangtse River which flows through a series of great gorges cut through the eastern mountains.

The Red basin is mostly a hilly region of topographic maturity. Local relief of 300 or more feet is common and some conspicuous ridges rise more than 1,000 feet higher than the streams. Outcrops are numerous in many parts and strat-

[1] Presented by title before the Association at Dallas, March 22–23, 1944. Manuscript received, May 12, 1944. Much of the information presented here has been abstracted and adapted from the works listed in the appended bibliography.

[2] Illinois State Geological Survey.

igraphic sections are well exposed along some of the steeply incised valleys. Structure is reflected to a considerable degree by topography, and the artificially terraced hillside fields commonly are controlled by the outcrops of resistant beds. The Chengtu plain in the northwestern part is a large alluvial fan deposited by the Min River, and the only considerable area of level land. Roads are few and the rivers constitute the principal arteries of traffic.

Stratigraphy.—Cretaceous redbeds are the surface rocks throughout most of the basin. Younger redbeds possibly Tertiary in age occur in some areas. Jurassic and Triassic strata crop out along the axes of some of the larger anticlines. Older beds come to the surface within the basin at only a very few places and are known mainly from exposures in the surrounding mountains. A generalized section of the formations exposed within the basin, penetrated by the brine wells and exposed at Omei Shan on the southwest margin of the basin, is as follows.

	Feet
Tertiary (?)	
Chengtsiangyen formation	3,000
Soft brick-red sandstone and shale with conglomerates in lower part	
Cretaceous	
Chiating formation	1,500
Purplish red sandstone and shale	
Tzuliuching formation	3,500
Greenish gray sandstone and greenish, brownish, or reddish shale with thin layers of limestone in lower part	
Jurassic	
Hsiangchi formation	1,500
Grayish brown sandstone with shale and thin workable coal seams	
Triassic	
Chialingchiang formation	1,400
Thick- to thin-bedded dolomitic limestone, shaly above	
Feihsienkuan formation	700
Purplish to reddish sandstone and shale with thin limestone layers in upper part	
Permian	
Omeishan basalt	1,100
Dark greenish gray lava flows, weathering reddish or brownish, partly amygdaloidal or porphyritic	
Chisia formation	1,300
Massive gray bituminous and partly cherty limestone and interbedded dark shale	
Ordovician	
Tachengssu formation	500
Quartzitic sandstone, reddish to purplish brown below, yellowish gray above and greenish sandy shale	
Cambrian	
Hsiasiangchih formation	700
Gray impure partly conglomeratic limestone and calcareous shale	
Yiehsienssu formation	450
Gray, partly calcareous shale, gray partly oölitic limestone, and quartzitic sandstone, locally with thin-bedded red sandstone at top	
Chiulaotung formation	750
Purplish to dark gray shale and sandstone with some thin-bedded limestone in lower part	
Sinian	
Hungchunping formation	2,500
Light to dark gray crystalline siliceous limestone without chert	
Pre-Sinian	
Coarse-grained greenish gray granite with pink and greenish feldspar	

This section of the pre-Triassic rocks is certainly not characteristic of the entire Red basin. The Omeishan basalt is known only on the southwestern border

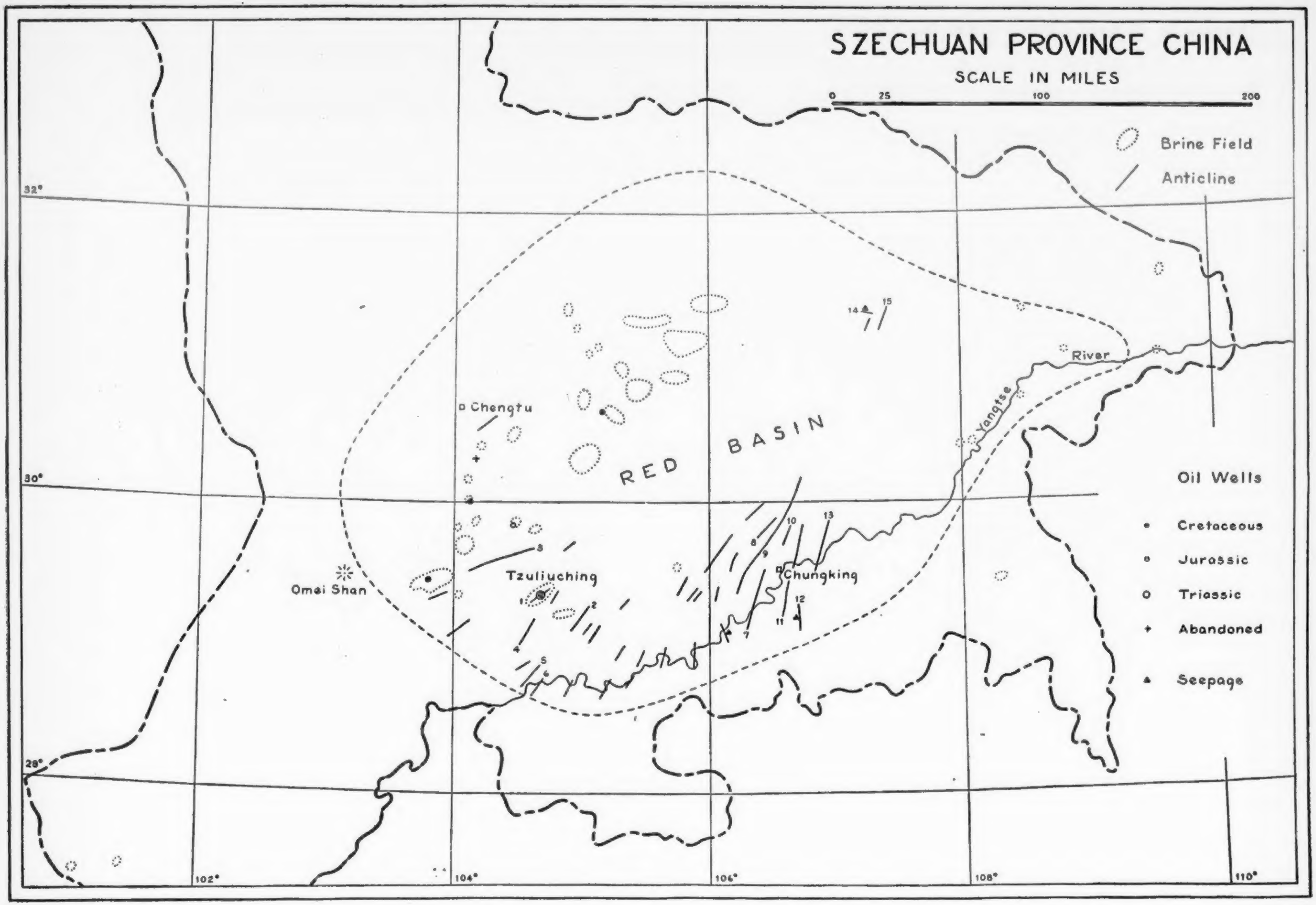

FIG. 1.—Red basin of Szechuan showing anticlinal axes, brine fields, and oil occurrences. Anticlines are numbered to correspond with cross sections.

and in the mountains farther south and west. It probably does not extend any great distance into the basin beneath younger beds. Likewise, the hiatus between Ordovician and Permian formations may be so important only locally. North of the basin, a very thick section intervenes, consisting of 15,000 feet of Devonian quartzite grading upward into massive limestone, and 1,500 feet of Silurian greenish shale with nodular limestone. Carboniferous strata are present east and southeast of the Red Basin, and, in the highlands of Kweichow province, the Mississippian and Pennsylvanian systems are each represented by about 2,500 feet of limestone, shale and sandstone. The lack of detailed field work on the Szechuan borders makes impossible at this time any reasonably accurate estimate about the distribution of any of these formations, but each of them is probably present beneath some part of the basin.

Structure.—The strata of the southern part of the Red basin are arched into a series of anticlines, some of which are conspicuous because of their strong influ-

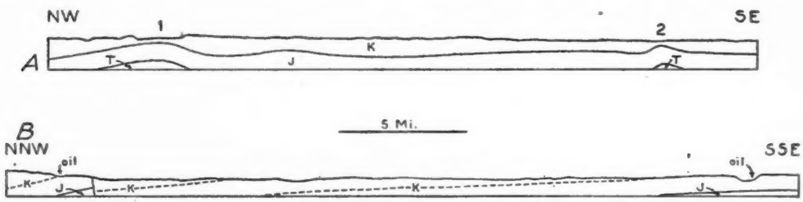

FIG. 2.—Cross sections: *A*, southeast from Tzuliuching; and *B*, through oil localities 35 and 55 miles, respectively, northwest of Tzuliuching; after T'an and Lee. Vertical scale twice horizontal. T, Triassic; J, Jurassic; K, Cretaceous.

ence on local topography. In general they trend northeast-southwest, are asymmetrical and become progressively narrower and more compressed eastward. Hot springs issue from the crests of several of the narrower structures. Most of the anticlines in the western half of the basin have steeper eastern flanks and most of those in the eastern half are steeper on the west. Many of the synclines are broad and contain gently dipping or nearly horizontal beds. In details, however, the structures vary greatly and there are numerous exceptions to all of the foregoing generalizations.

Structural disturbance in most parts of China was so pronounced that dips of less than 30° are commonly considered gentle, and dips lower than 10° may be ignored as insignificant unless they uniformly prevail in large areas. Consequently other anticlines less pronounced than those indicated on the accompanying map probably also occur in the southern part of the Red basin. Likewise, it should be emphasized that most of the recorded structures have been examined only in the course of route-traverse surveys and their extent and continuity or relationship to structures noted on other traverses are generally not known. That part of the basin south of the highway between Chunking and Chengtu and north of the

Yangtse River has been most investigated and the absence of structures on the map elsewhere is probably much more an indication of lack of knowledge than of actual structural simplicity, particularly in the eastern part of the basin. Perhaps an exception to this last observation is the region of the brine fields east of Chengtu where, it is recorded,

> No conspicuous structures were found . . . slight undulation and gentle inclination of strata are the only prevailing features, while in some parts the strata are flat-lying. When the strata are inclined the inclination is scarcely more than five degrees, so that it is difficult to define definite structure with such variable undulation.[3]

BRINE FIELDS

Szechuan province has long been noted for its salt industry which has been in continuous operation for more than 2,000 years. It is said that salt was obtained originally from brine springs and when these ceased to flow as the result of an

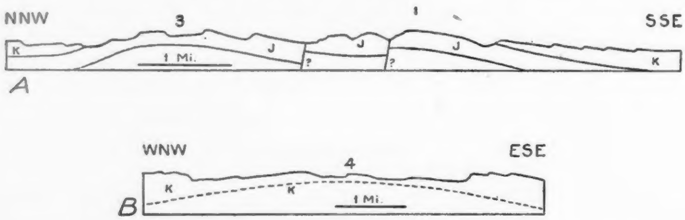

FIG. 3.—Cross sections: *A*, 25 miles northwest of Tzuliuching, and *B*, 20 miles south of Tzuliuching; after Heim. Horizontal and vertical scales equal. J, Jurassic; K, Cretaceous.

earthquake drilling was invented. Since the earliest time, drilling methods have remained practically unchanged. Crude cable tools are used and power is furnished by coolies who step on and off the beam. Progress of 1–3 feet is made per day at shallow depth.

Many thousands of brine wells have been drilled in all parts of the Red basin but much of the salt industry is now confined to more or less well marked fields in its western half. The Tzuliuching field is much the most important and accounts for approximately 90 per cent of the production in the province. Wells vary from 100 to more than 4,000 feet in depth and are generally 3–8 inches in diameter except near the surface where they may widen to 16 inches. At the top, wells are cased with bored stones, wooden pipe, or large bamboos but below 100 feet the hole is generally open although a lining of putty is used in some wells to prevent caving. The deeper wells are surmounted by tripod derricks made of bundles of pine poles bound together with rope; some of them reach a height of 125 feet. Brine is raised in bailers of bamboo or sheet metal and the latter may be 100 feet long. Bamboo pipe lines are commonly used to carry brine from wells to evaporating plants.

[3] T'an and Lee, "Oil fields in Szechuan Province", *Geol. Survey China Bull.* 22 (1933), p. 66.

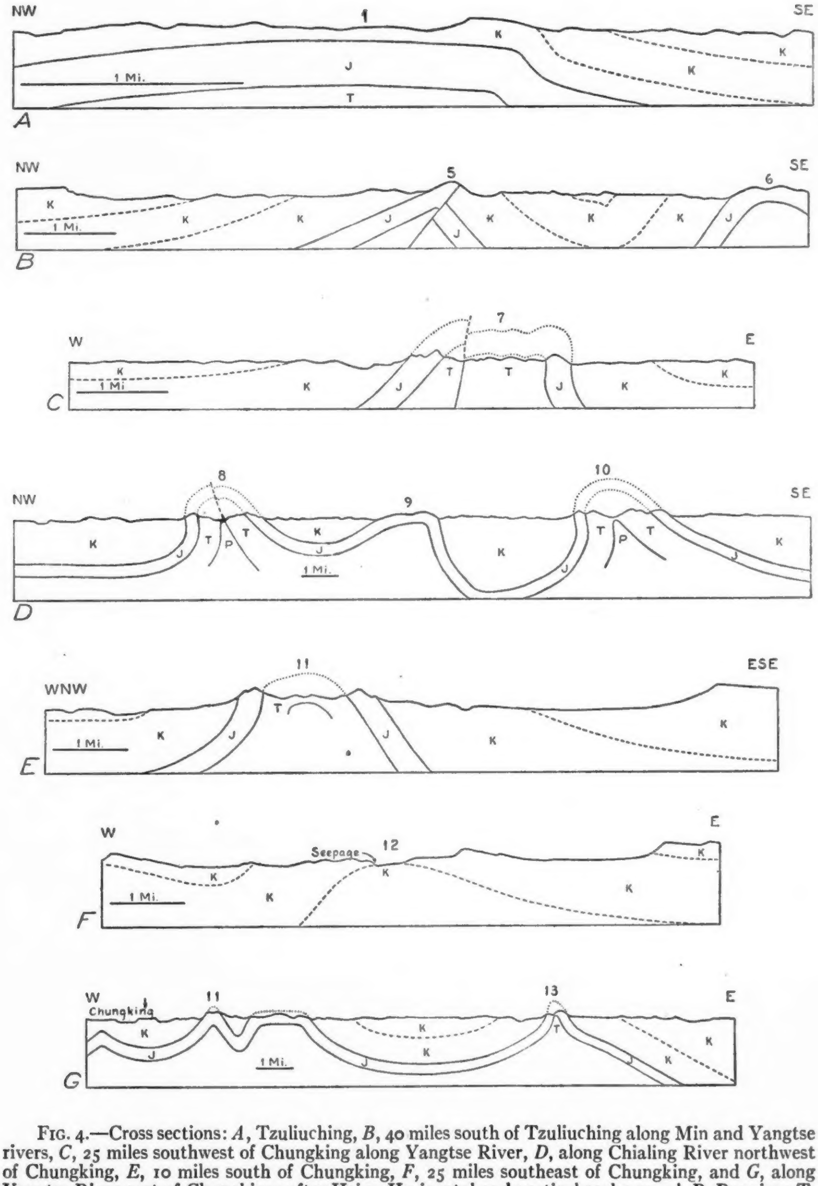

FIG. 4.—Cross sections: *A*, Tzuliuching, *B*, 40 miles south of Tzuliuching along Min and Yangtse rivers, *C*, 25 miles southwest of Chungking along Yangtse River, *D*, along Chialing River northwest of Chungking, *E*, 10 miles south of Chungking, *F*, 25 miles southeast of Chungking, and *G*, along Yangtse River east of Chungking; after Heim. Horizontal and vertical scales equal. P, Permian; T, Triassic; J, Jurassic; K, Cretaceous.

Oil and gas have been produced in small quantities from wells drilled for brine in several different fields. Information obtained from the wells is also important in the subsurface identification of formations and because several of the more important fields are located on the crests of anticlines.

OIL AND GAS

Seepages.—Three oil seepages are known in the eastern part of the Red basin. One is about 25 miles southeast of Chungking near the crest of an anticline in the Cretaceous Tzuliuching formation (Fig. 4F). About one barrel of oil per month is recovered here from a shallow pit. A second seepage occurs about 130 miles northeast of Chungking on the northwest side of a dome whose axis extends at right

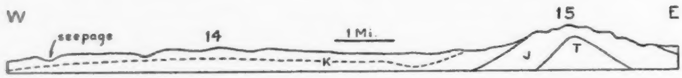

FIG. 5.—Cross section 130 miles northeast of Chungking, after Lee. Vertical scale twice horizontal. T, Triassic; J, Jurassic; K, Cretaceous.

angles to the prevailing structure of the region (Fig. 5). The Tzuliuching formation is also at the surface here and production is about one pint per day. The third seepage is reported about 40 miles southwest of Chungking, but its exact location is not known and it has not been visited by geologists. In addition, hard brittle bituminous material is reported to occur in the western part of the basin near Chengtu.

Gas seepages are reported to be numerous but they have not been described nor their locations recorded.

Wells.—No accurate records have been kept regarding the discovery or occurrence of oil in the brine wells of Szechuan. The earliest known account dates from the middle of the Ming dynasty, 400–500 years ago, in which the presence of oil about 50 miles west of Tzuliuching is mentioned. Gas, however, has been known and probably used for nearly 2,000 years.

Numerous wells in Szechuan are known as productive oil wells. The greatest actual production of a single well, however, was about 10 barrels per day and the "production" of most others can be measured only in pints. Even such small quantities are important because of the relative value of the oil as compared with wages.

Gas, generally under very low pressure, appears to be somewhat more widespread in its occurrence than oil, but very little information is available. No measurements of pressure or quantity of gas have ever been made. One well, however, is reported to have furnished enough gas for 375 evaporating pans, each $4\frac{1}{2}$–5 feet in diameter, for 7 years without being exhausted and it is said another produced even more.

Oil-bearing beds.—In the Tzuliuching brine field oil has been noted at five horizons: (1) lower part of the Triassic Chialingchiang limestone, (2) upper part of the same, (3) lower part of the Jurassic Hsiangchi formation, (4) about 250 feet higher in the same, and (5) basal beds of the Cretaceous Tzuliuching formation. This is the only brine field where drilling has penetrated the Triassic. Although definite correlations can not be made, oil showings have been encountered at similar, higher formations in other brine fields and small amounts of oil have also been found in the (6) upper part of the Hsiangchi formation, and (7) higher in the Tzuliuching formation.

Relation to structure.—The distribution of oil-producing wells is not particularly revealing as far as structure is concerned. At Tzuliuching the brine field is located on the crest of a well marked anticline (Figs. 2A and 4A). Wells 50 miles farther west are a considerable distance down on the flank of an anticline where no notable structural irregularity occurs. Northwest of Tzuliuching about 35 miles the strata dip 3°–5° NW. and no indication of an anticline has been recognized (Fig. 2B). At the next locality, about 25 miles farther, there is a normal fault where the northwest dip increases to 10° and the "oil well" is situated on the upthrown side (Fig. 2B). East of Chengtu 160 miles, the strata are nearly horizontal but undulate slightly and a broad gentle anticline may be present.

Oil tests.—In 1938 an oil test was drilled by the Chinese Government near the seepage 25 miles southeast of Chungking. It was about 3,000 feet deep, beginning in the Cretaceous redbeds and ending in the Triassic limestone. Later, a second well was drilled north of Tzuliuching where an anticline brings the Triassic limestone to the surface and a gas seepage occurs. It also was about 3,000 feet deep and penetrated the Permian limestone. Both wells were failures and not even a showing was recognized in either. A third test at another locality is now reported to be drilling.

Character of oil.—Simple tests on samples collected in Szechuan show that the API gravity of the oil as received in the laboratory varied from about 20° to 54°. On the basis of these tests the petroleum from five localities may be separated into three groups.

The first group of samples was obtained from the wells at Tzuliuching and brine fields 35 miles northwest and 55 miles west of that locality. These samples varied from 28.5° to 39° gravity, were green by reflected light and brown by transmitted light, and had a paraffine base. By simple distillation they yielded up to 17.7 per cent gasoline and 13.5 to 49.8 per cent kerosene. Too much significance should not be placed on the low yield of gasoline from some samples because a considerable part of their light fractions may have been lost by evaporation before recovery. Curiously, however, two samples from a single well in the Tzuliuching area were highest in gravity (37.5° and 39°) and lowest in gasoline yield (0.54 per cent).

Oil of a different type occurs at the seepage 25 miles southeast of Chungking. Two samples had gravities of about 20° and 23.5°, respectively. This oil is very

dark-colored and has an intermediate paraffine-asphaltic base. By distillation no gasoline or kerosene was produced and it has obviously lost its lighter constituents by prolonged evaporation.

Oil of the third type is recovered from wells 65 miles east of Chengtu. It has a gravity of about 54°, is clear and transparent with a light yellowish color, and looks much like refined kerosene. No distillation tests have been made.

Source.—All of the post-Triassic strata in the Red basin are believed to be non-marine and, although coal seams are present in the Jurassic, they appear to include no possible source beds from which the petroleum encountered in some of the brine wells could have been derived. Consequently, this oil probably originated in the Triassic marine limestone which not only contains oil at the Tzuliuching brine field but is also reported to be somewhat petroliferous where it crops out in central Kweichow province. The possibility that oil in the Jurassic and Cretaceous formations has migrated upward from the Triassic along numerous small faults that are known to exist is suggested by the upward decrease in salinity of brines obtained at different horizons. Rock salt occurs interbedded in the Triassic limestone and natural brine obtained from that formation contains 17.1–26.6 per cent of salt (average 21.6). Also at Tzuliuching, the salt in Jurassic brine varies from 8 to 14.6 per cent and brine from the base of the Cretaceous contains only 2.5 per cent salt.

There is no evidence, however, of migration upward from older beds into the Triassic limestone, and water obtained from the underlying Feihsienkuan formation at Tzuliuching is almost fresh.

CONCLUSIONS

Although small amounts of oil and gas are widely distributed throughout the Red basin of Szechuan the information now available is not particularly encouraging about the possibility of Mesozoic production. Structurally the Tzuliuching anticline is ideal and the failure of the numerous brine wells there to find oil in appreciable quantity is certainly disappointing. However, this is the only locality in the basin where the Triassic limestone, the most probable source of the known oil, has been thoroughly tested and failure there can not entirely condemn other favorable structures.

It has been suggested that the brine wells were inadequate oil tests because they were drilled without casing and the heavy brine may not only have prevented the entrance of oil into the wells but may even have forced oil back into the sands. Although this might have occurred in individual wells it is extremely unlikely that oil would not have been found in such a closely drilled field as Tzuliuching if it were present there in large amounts. Moreover, brine has been bailed from this and other fields so persistently and for so long a time that the brine level has been greatly reduced and some formerly productive zones have actually gone dry so that wells had to be deepened or abandoned. Under such conditions of lessened pressure oil, if present, should have appeared in some of

the wells. Consequently, it is certain that no oil pool exists at Tzuliuching in the Triassic limestone or any higher formation.

The Red basin, however, possesses other possibilities for production that are as yet largely untested and appear to have been little considered. These are provided by the almost unknown Paleozoic rocks that underlie the basin. Of primary interest and importance is the Permian limestone that is probably everywhere present. This formation is known in the surrounding mountains where it contains bituminous and carbonaceous beds including coals. The main part of the formation consists of limestone similar to strata that are productive in some other parts of the world. Tests to the Permian will be comparatively deep but it can be reached at approximately 5,000 feet at Tzuliuching. It is probably somewhat shallower at some other almost equally favorable structures and is certainly much closer to the surface on some of the more compressed anticlines in the eastern half of the basin. Finally, older strata of Devonian, Silurian and Ordovician ages which probably underlie considerable but unknown parts of the basin are not without additional possibilities.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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PRINCIPAL SEDIMENTARY BASINS IN THE EAST INDIES[1]

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New York, N. Y.

An over-all picture of the undiscovered oil resources of the East Indies involves an evaluation of five large islands and nearly two score of smaller ones, totalling 735,000 square miles—an area twice as large as Texas,—spread over a region larger than the United States. The topographic and geologic conditions are as varied as those of the United States but the interpretation of the general geologic conditions is more difficult because of the large gaps in areal geology between the islands. Furthermore, many of the islands lie along the earth's greatest island arc which in Tertiary and Quaternary time was subject to periodic oscillation and at the end of the Pliocene to great diastrophism which has locally uplifted Eocene and Oligocene strata to 19,000 feet above sea-level. The island arc was also subjected, in one part or another, during the entire Tertiary, to considerable volcanism which continues to the present day.

The problem, however, is somewhat simplified because the oil possibilities of the East Indies lie almost entirely in sediments of Tertiary age. A number of islands, especially those along the island arc, are largely geanticlines. Pre-Tertiary rocks, chiefly complexes of rock of all kinds and of all ages are generally exposed in the cores of the geanticlines which are flanked by greater or smaller portions of the adjacent Tertiary geosynclines. The larger islands of Sumatra, Borneo, and New Guinea lie, in part, on the edge of the stable forelands of Asia and Australia from which landmasses a large part of the Tertiary sediments was primarily derived. The other islands lie along arcs bordering the old landmasses.

The Tertiary is nearly everywhere unconformable on older rocks, and the basal transgressive strata, including both terrestrial and marine sediments, range in age from Eocene to Pliocene. In some areas a great part of the Tertiary is present, with few breaks, and reaches thicknesses of 10,000–12,000 meters locally. In other areas only Miocene and Pliocene are present, with thicknesses varying from 500 meters to 9,000 meters.

The geosynclines reached their greatest extent in the late Oligocene and lower Miocene when marine sediments were almost universally deposited. In the upper Miocene gentle warping and erosion began in some areas, followed locally by subsequent transgressions in the late Pliocene and Pleistocene. The upper Miocene was a period of intermingling marine, brackish-water and fresh-water deposits. In the Pliocene the geosynclines were evidently broken into a number of local basins in which, over the greater part of Sumatra, Borneo, New Guinea, and part of Java, chiefly terrestrial sediments were laid down whereas in other areas the deposition was marine, consisting almost entirely of thick foraminiferal marls and clays, with some limestones. Orogenesis began at the end of the Pliocene in

[1] Manuscript received, May 12, 1944.

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some areas and continued well into the Quaternary with a great transgression again taking place in the late Pleistocene, especially around the old landmasses of Asia and Australia.

By the end of 1940 nearly 1 billion barrels of oil had been produced in the East Indies. Production began in 1889 and until 1922 it was obtained from the upper Miocene and Pliocene. In 1922 commercial oil was found in south Sumatra in the Aquitanian (upper Oligocene or lower Miocene), and since that time it is estimated that the Aquitanian produced 168 million barrels of oil, or about 17 per cent of the total East Indies production. In 1939 oil was found in the Eocene in south Borneo but it has not yet been developed commercially. Annual production in the East Indies amounted to 39 and 41 million barrels in 1929 and 1930, respectively. This increased steadily through a decade until it reached 60 million barrels in 1939 and 1940.

The production of oil from the several districts in the East Indies is given in the following table.

TOTAL PRODUCTION OF CRUDE OIL AND CASINGHEAD GASOLINE IN EAST INDIES—TO DECEMBER 31, 1940

Region	*Production Began*	*Age of Producing Formations*		*Production in Barrels*
North Sumatra	1892	Pliocene		142,779,224
Djambi	1923	Upper Miocene and Pliocene		54,601,783
South Sumatra	1898	Upper Miocene and Pliocene	113,599,361	281,668,685
		Aquitanian	168,069,324	
Java and Madoera	1889	Miocene and Pliocene		108,002,410
North Borneo (Tarakan and P. Boenjoe)	1906	Pliocene		143,725,407
East Borneo (Samarinda)	1898	Chiefly Miocene		238,607,148
South Borneo (Tandjoeng)	1939	Eocene		30,030
Ceram	1913	(?)		7,474,371
		Total Netherlands Indies		976,889,058
British Borneo Sarawak and Brunei	1913	Miocene?		101,168,000
		Total East Indies		1,078,057,058

Most of the attractive and more accessible structures in the Miocene and Pliocene have been tested, except in New Guinea, and remaining structural prospects lie in less attractive, complicated structures: structures with small or doubtful closures; structures situated in remote areas; or structures concealed by alluvium or by unconformable horizontal strata. The Lower Tertiary, especially the Eocene, is of interest in Borneo, and all areas where the Eocene is under cover and within reach of the drill should be explored. The Mesozoic, including the Triassic in Timor and Boeton and the Cretaceous in New Guinea, has some oil indications, but it is of subordinate interest at present because of structural conditions and the limited areal extent of the prospective territory.

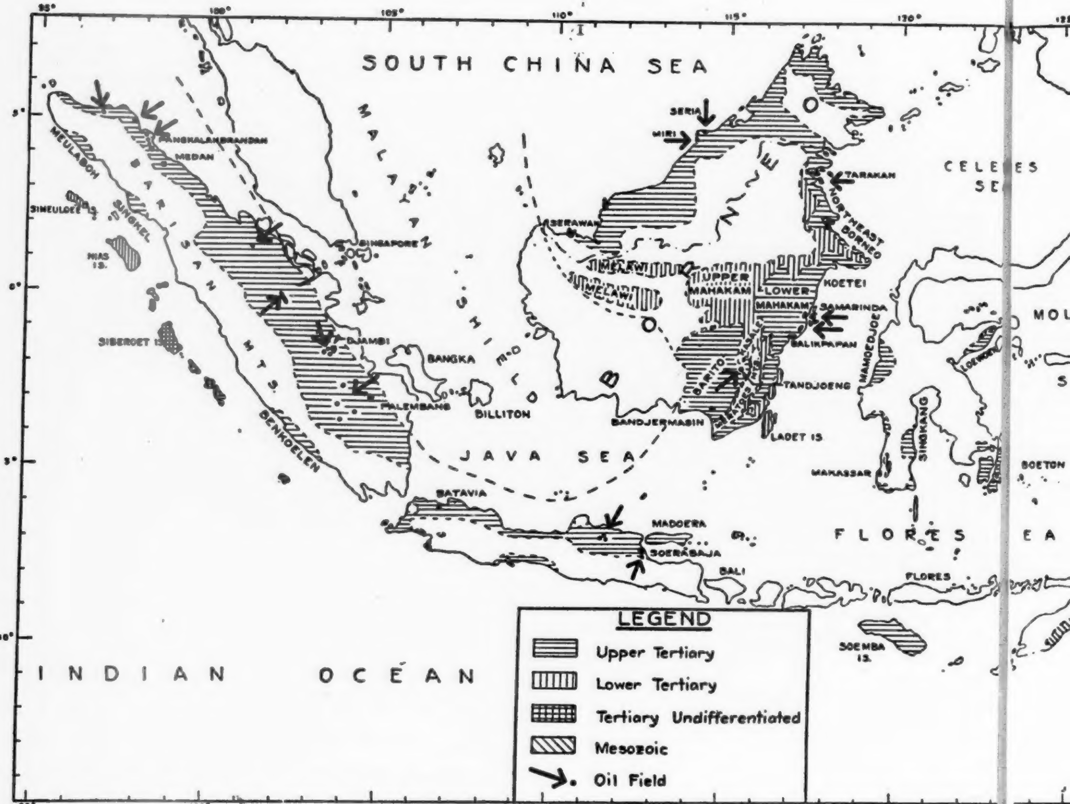
SOUTH CHINA SEA
CELEBES SEA
JAVA SEA
FLORES SEA
INDIAN OCEAN
MALAYA
BORNEO
BARISAN MTS.
MEULABOH
SINGKEL
SIMEULOEE IS.
NIAS IS.
SIBEROET IS.
BENKOELEN
PANGKALANBRANDAN
MEDAN
SINGAPORE
DJAMBI
BANGKA
PALEMBANG
BILLITON
BATAVIA
MADOERA
SOERABAJA
BALI
FLORES
SOEMBA IS.
SERIA
MIRI
SERAWAK
MELAWI
UPPER MAHAKAM
LOWER MAHAKAM
KOETEI
SAMARINDA
BALIKPAPAN
TARAKAN
NORTHEAST BORNEO
BARITO
TANDJOENG
BANDJERMASIN
LADET IS
MAKASSAR
SINGKANG
BOETON
LEGEND
Upper Tertiary
Lower Tertiary
Tertiary Undifferentiated
Mesozoic
Oil Field

FIG.

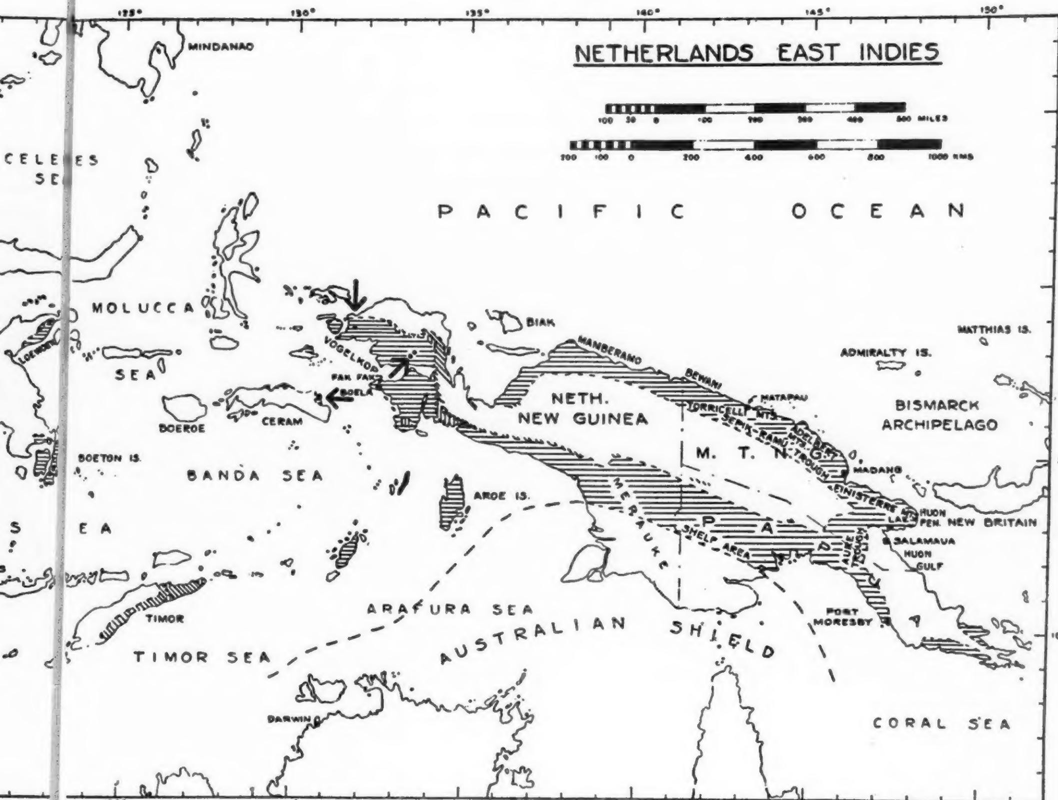
NETHERLANDS EAST INDIES
PACIFIC OCEAN
MINDANAO
CELEBES SEA
MOLUCCA SEA
BIAK
MANBERANO
VOGELKOP
FAK FAK
BOELA
BOEROE
CERAM
NETH. NEW GUINEA
ADMIRALTY IS.
MATTHIAS IS.
BISMARCK ARCHIPELAGO
MATAPAU
TORRICELLI MTS.
SEPIK-RAMU TROUGH
M. T. N. G.
MADANG
FINISTERRE MTS.
HUON PEN.
NEW BRITAIN
SALAMAUA
HUON GULF
BOETON IS.
BANDA SEA
AROE IS.
MERAUKE
SHELF AREA
PAPUA
AURE TROUGH
TIMOR
TIMOR SEA
ARAFURA SEA
AUSTRALIAN SHIELD
PORT MORESBY
DARWIN
CORAL SEA
MILES
KMS

FIG.

In addition to structural prospects, stratigraphic traps are present but they have only recently received attention in a few areas, namely, Sumatra and Borneo. The prerequisites for stratigraphic traps, that is, unconformities, disconformities, wedge belts of porosity and variation in thickness, are commonly present. The Tertiary strata generally lie with marked unconformity on a complex of igneous and metamorphic rocks and Mesozoic sediments. The basal Tertiary transgression is marked by a great overlap in some areas, and since the overlapped basal beds contain source rocks in some regions, stratigraphic traps may occur at this unconformity. In some extensive regions this unconformity can be reached by the drill but in other areas the section is too great to be penetrated. Other disconformities or low-angle unconformities are present locally in the Eocene and Oligocene, but relatively little is known of the stratigraphy of this part of the section, since interest was chiefly concentrated on the Upper Tertiary until recently. An unconformity between the Pliocene and Miocene is present in a number of areas, and while no production is known from stratigraphic traps formed at this break it merits attention.

It is probable that further drilling, together with the pooling of stratigraphic information by the several oil companies will lead to the recognition of other unconformities or disconformities within the Tertiary. The amount of wildcat drilling, even in the best explored basin, south Sumatra, is on the order of one well to 75–100 square miles, as compared with one well per 1.8 –10 square miles in the several basins of the United States.

SUMATRA

Sumatra, approximately as large as California, has produced nearly 500 million barrels of oil, or half the total production in the East Indies.

The broad tectonic features of this island are relatively simple. The Barisan Mountains, which traverse the western third of the island from northwest to southeast, constitute a geanticlinal borderland which is paralleled on the east by a great asymmetric geosyncline that was hinged on the Malay Peninsula, the foreland of Asia during the Tertiary. In north Sumatra, only a narrow part of the geosyncline is present, the greater part having been transgressed by the sea (Malacca Strait) in the late Pleistocene. In central and south Sumatra, on the other hand, the greater part of the geosyncline is present. Rocks of the foreland that are extensively in evidence on the Malay Peninsula, on the group of islands south of Singapore, and on the large islands of Banka and Billiton, are very sparsely exposed along the east coast of Sumatra.

The age sequence and lithologic character generally are remarkably uniform throughout the Sumatra geosyncline, but the thickness of the strata, as well as the degree of folding vary greatly. The greater thicknesses occur in the west near the borderland. They are also greater in the north than in the south as shown by the following table.

	Meters
North Sumatra: Pliocene, Miocene, some Eocene locally	7,500–9,400
Central Sumatra: Pliocene and Miocene	2,350–3,500
South Sumatra: Pliocene and Miocene	600–4,350

Folding is greatest along the Barisan borderland whereas along the Malayan foreland the folds are gentler and in some areas there is little or no folding. Oil source beds are believed to occur in the Miocene, though oil indications occur in all formations. Practically all exposed moderately to gently folded closed anticlines have been tested, and, for the greater part, conclusively in south and central Sumatra where the entire section has generally been penetrated. In north Sumatra very steep, high structures along the mountains outnumber the gentler folds of the coastal region. Few of these high structures have been tested because of the erosion of the oil measures and the probable general absence of reservoir beds in the lower parts of the section. In the gentler structures along the north coast no wells are known to have penetrated the entire Tertiary section, though several wells have been drilled to 8,000–10,000 feet.

Oil indications are numerous in the Miocene and Pliocene in north and south Sumatra, but in central Sumatra there is only one slight oil seep and this occurs at the very base of the section. Oil has been produced in north and south Sumatra for more than 40 years but in central Sumatra no discoveries were made until 1938.

The future oil possibilities of the Sumatra geosyncline lie chiefly in anticlinal structures concealed by unconformable Plio-Pleistocene strata, in stratigraphic traps and, in north Sumatra, in deeper formations not yet penetrated by the drill. Since the section is in the main conformable, stratigraphic traps probably will be related chiefly to the overlap of the Tertiary on the Malayan foreland, and probably will be limited to central and south Sumatra. In north Sumatra only the deeper part of the geosyncline is present and the section is too thick to be drilled for deep-lying stratigraphic-trap possibilities.

In central and south Sumatra there is evidence of considerable relief in the pre-Tertiary surface on which the Tertiary strata were deposited, and since source beds occur near the base of the section, topographic relief in the basal complex may be an important factor in accumulation.

The oil possibilities of the southwest coast of Sumatra, southwest of the Barisan Mountains, are limited to three embayments, probably structural, lying in the Meulaboh, Singkel, and Benkoelen regions. In the Meulaboh and Singkel areas, which are 30–40 kilometers wide and about 100–120 kilometers long, no oil indications are known and little can be learned of the section except by drilling, because young unconformable deposits cover practically all the Tertiary strata which are believed to lie in these embayments.

The Benkoelen embayment, 30–40 kilometers wide and more than 200 kilometers long, exposes a thick section of Miocene strata along the Barisan Mountains, which are similar in age and lithology to the lower part of the oil-bearing section in the east Sumatra geosyncline. Oil indications occur. In the wide coastal belt practically unfolded or gently homoclinal Plio-Pleistocene strata cover the Miocene.

The islands off the southwest coast of Sumatra, Nias, Simeuloe, and others, consist largely of terrestrial strata tentatively classified as Eocene, with some

marine Oligocene and Pliocene sediments,—all separated by unconformities or disconformities. The islands evidently mark a series of highs along a geanticlinal axis that parallels the Barisan axis of Sumatra. Oil indications are unknown.

JAVA

Java had produced more than 100 million barrels of oil to the end of 1940.

This island is not as regular structurally and stratigraphically as Sumatra, and it may lie largely in a different Tertiary geologic geosyncline. Although the core of the island is geanticlinal, only a few very small areas of pre-Tertiary strata appear, probably in part because of the late Tertiary and Quaternary volcanics which more extensively conceal the main geanticline than in Sumatra, and in part because of lesser uplift and denudation. There is a possibility that the Java geanticline is an extension of the Nias-Simeuloe axis rather than of the Sumatra geanticline as has usually be considered.

The Java geanticline chiefly exposes Miocene strata, and the volcanoes, therefore, lie on Tertiary platforms, whereas those in Sumatra lie chiefly on pre-Tertiary platforms. Like Sumatra, the Java geanticline is bordered on the north by a geosyncline, but the deeper and wider part lies on the eastern end of the island, whereas the deeper part in Sumatra lies on the northwestern end of that island. The shallower parts of the Sumatra and Java geosynclines, therefore, are adjacent to the "buried" extension of the Malay Peninsula around which the island arc is bent.

In west Java the Tertiary section along the north coast is on the order of 2,500–3,200 meters thick and is chiefly marine except near the top. The geosyncline is probably asymmetric, as in south Sumatra. In this region young, horizontal, unconformable Plio-Pleistocene strata cover a great part of the area in which oil possibilities are believed to be present, and geophysical surveys are necessary to obtain clues to the underlying structure. Surface oil indications occur in west Java and some good showings were found in wells drilled near Cheribon.

In east Java the exposed section and that penetrated in wells totals 3,100–3,700 meters but is probably much thicker, for 7,000 meters of Miocene and Oligocene are exposed and penetrated in wells in Madoera and 3,000 meters of Oligocene strata crop out in Kangean Island east of Madoera which are not in evidence on the latter island or on east Java.

The east Java and Madoera sections are chiefly marine marls and shales and have remarkably few porous beds. Sands are generally rare except locally in the upper part of the section, and limestones are also limited when the great thickness of marine sediments is considered. The section in east Java and Madoera is apparently conformable except for an unconformity in the Pliocene around and over the Rembang-Madoera geanticline which lies close to the north coast. The possibility of stratigraphic traps remains to be investigated.

The south coast of Java is underlain by a thick series of Miocene and Pliocene marls, clays, limestones, and volcanics. A few gas seepages occur.

BORNEO

Topographically and structurally Borneo is a complicated island and a submergence of about 200–300 feet would result in a radiating system of mountain chains separated by gulfs, like the island of Celebes. It is also noteworthy that Borneo has a regional position similar to that of Sumatra, that is, it borders and includes part of the foreland of Asia. During the Eocene and Oligocene thick terrestrial sediments and volcanics were deposited around the foreland in west, central, and southeast Borneo, and marine deposits, chiefly shales, limestones and sandstones 6,000–10,000 meters thick, were deposited in central Borneo and east Borneo where a great embayment persisted throughout most of Lower Tertiary time. At the beginning of the Miocene marine strata became more and more interbedded with fresh-water deposits containing coal beds, which increase upward until, in the Pliocene, practically the entire section consists of terrestrial deposits, except in the Sangkoelirang Bay-Mangkalihat region where the Pliocene is composed chiefly of foraminiferal clays, marls, and limestones.

During the late Miocene, uplift began along the western border of the geosyncline, also in the regions now occupied by the Meratoes Mountains of southeast Borneo and by the Mangkalihat Peninsula. These uplifts divided the geosyncline into three embayments in which deposition continued until the late Pliocene, when the orogenesis began that produced the several radiating mountain ranges of Borneo and folded and faulted the intervening geosynclines. Only gentle folding and faulting occurred in the shelf areas near the foreland, whereas steep folding took place in the central parts of the basins where the sections are very thick.

The only oil indications in the Lower Tertiary occur in the Eocene at three localities, namely, in the Barito, Melawi, and the upper Mahakam River areas, all situated relatively close to the border of the sedimentary basin. The Upper Tertiary (Miocene and Pliocene) contains numerous oil indications in the Barito, Mahakam, and northeast Borneo areas.

Barito River Basin.—This part of Borneo is structurally so analogous to south Sumatra that it was believed by some to be a continuation of that geological province. There is some paleontologic and structural evidence, however, that they were not connected and that each represents a separate embayment from the Indian Ocean. On the west or foreland side of the Barito Basin the section is very thin, only some hundreds of meters thick, and apparently little folded. Toward the east the section thickens to 2,000 meters or more near the Meratoes Mountains which form a borderland like the Barisan Mountains in Sumatra. The island of Poeloe Laoet seems analogous structurally and stratigraphically to the islands off the west coast of Sumatra. In the Borneo province, however, all these features are on a smaller scale and the Barito Basin is generally without anticlines. The strata are sharply upturned in a relatively narrow belt along the Meratoes and Kasale mountains. The Miocene and Eocene oil seeps of this area occur in these upturned beds. Little is known about intra-Tertiary disconformities but it is

believed that one or two breaks occur in the section, at least locally. A disconformity appears to be present at the base of the Miocene and another at the base of the Pliocene.

Quaternary deposits almost completely cover the Tertiary in this region, and extensive geophysical exploration and exploratory drilling are necessary to develop the area.

Melawi River Basin.—This basin lies in west Borneo and includes the western end of a Lower Tertiary embayment in which thick terrestrial deposits and volcanics occur interbedded with some brackish-water deposits. One report states that some marine strata are present but another authority discredits this. The age of the sediments is not definitely known but they probably include some Eocene and much Oligocene. The 4,500–9,700 meter section contains nearly 1,000 meters of shale and includes quartzitic sandstones and thick volcanics. The Lower Tertiary lies unconformably upon a basement which includes some folded Cretaceous sediments. An oil seep occurs in the eastern end of the Melawi River Basin in shales of presumed Eocene age. Intrusions are common in the Lower Tertiary, and even numerous in some areas.

Upper Mahakam River Basin.—The upper Mahakam River Basin and also the headwaters of the Barito River are underlain by Eocene and Oligocene sandstones, shales, and limestones which are gently to moderately folded and faulted. These sediments are chiefly marine except at the base, and are believed to lie in the outer part of the same basin in which the Lower Tertiary terrestrial and brackish water sediments of the Melawi area were deposited. The section is 7,600–11,600 meters thick. A few gas seeps occur.

Insufficient work has been done in the upper Barito-upper Mahakam Basin to determine whether unconformities other than that at the base of the Tertiary are present which may serve as stratigraphic traps.

Lower Mahakam River Basin.—The Samarinda oil fields of this region had produced 238,600,000 barrels of oil to the end of 1940, or about one-quarter of the production of the East Indies.

This area is underlain by strongly folded strata which include Miocene marine sediments interbedded with terrestrial deposits and Pliocene sediments which are chiefly terrestrial. Oil indications occur in the middle and upper Miocene and Pliocene. The oil fields occur on the outer or coastal lines of structures where these strata lie under cover.

Central Mahakam River Basin.—Some interest was being shown before the war in the great central Mahakam River Basin which is floored to a predominating extent with Recent alluvial deposits or covered by great marshes and shallow lakes. Around the margins of this basin the exposed strata are steeply folded. The section appears to be largely conformable and the borders of the geosyncline apparently lie outside this area. Wedge belts of porosity quite probably occur in the section which is composed of interbedded marine and fresh- or brackish-water deposits.

Apar-Laoet geosyncline.—This geosyncline lies along the east coast of Borneo, south of the Mahakam River area, and extends to Poeloe Laoet, an island off southeast Borneo. It is apparently a structural geosyncline rather than a separate basin of deposition. The Miocene and younger oil measures have been largely eroded. The section, which totals, 4,800 meters, consists chiefly of Eocene sandstones and shales with coal beds, Oligocene limestones, and lower Miocene shales and sands. Folding and faulting are present. Oil indications occur only in the north, near Apar Bay.

Koetei area.—This area includes the Sangkoelirang Bay region in which the Miocene and Pliocene consist chiefly of foraminiferal marls and clays and some-limestones, as well as the Koetei district proper, south of the bay, where the section includes thick terrestrial sediments and is similar to that in the Samarinda region. Oil seeps occur in the upper Miocene and Pliocene. Numerous faulted anticlines are present.

The inner part of this area, which is essentially a northern continuation of the upper Mahakam Tertiary Basin, is underlain by thick Oligocene and Eocene shales and sandstones. Oil indications are unknown.

The average composite section in the Koetei area measures 3,865 meters of Upper Tertiary and more than 9,000 meters of Lower Tertiary. Sandstones and shale prevail in the Eocene and limestones in the Oligocene. The general structure as well as the stratigraphy of most of the Koetei area is similar to that of the Samarinda region.

Northeast Borneo.—This unit includes the embayment that lies north of the Mangkalihat Peninsula, a mountainous region which exposes Eocene and Oligocene limestones, sandstones, and shales. It includes the Tarakan Island field which had produced 143,700,000 barrels of oil to the end of 1940, representing $\frac{1}{7}$ of the total East Indies production. The Tarakan oil is from the Pliocene which lies unconformably on the Miocene.

The northeast Borneo Basin is relatively narrow and much of the Upper Tertiary is covered by the Recent flood plains of several great rivers.

The section includes more than 4,000 meters of Eocene and Oligocene shales, limestones, and sandstones, in which there are no oil indications, and more than 5,000 meters of Miocene and Pliocene marine and fresh-water deposits, including sandstones, shales, marls, and coal beds. Numerous oil indications occur in the Pliocene; only one small oil seep and a few gas seeps are known in the Miocene.

British Borneo.—British Borneo includes Sarawak, Brunei, and British North Borneo. Two oilfields occur in this region; the Miri field, situated in Sarawak, and the Seria field, situated in Brunei, about 50 kilometers from Miri. Production began in Miri in 1913, whereas Seria was discovered in 1928. The cumulative production of these fields totaled slightly more than 100 million barrels at the end of 1940. In 1940 the average daily production at Miri was about 3,600 barrels and at Seria about 15,700 barrels.

Tertiary strata ranging in age from the Eocene to the Pliocene are exposed in

a belt 50–75 kilometers wide along the northwest and northeast coasts of British Borneo. The information available on the stratigraphy of British Borneo is so fragmentary, however, that further comment is impracticable.

Widespread oil indications occur in the Miocene.

CELEBES

The several arms of Celebes are geanticlines, the cores of which chiefly expose pre-Tertiary igneous and metamorphic rock, with Eocene limestone locally present. These arms are bordered by a number of narrow Tertiary embayments which are of importance at only three places, each varying from 70 to 130 kilometers in length. The Mamoedjoe embayment, on the west coast, is structurally complicated and the section includes Eocene, Oligocene, Miocene, and Pliocene strata, probably with unconformities at the base of the Pliocene and at the base of the Miocene (Aquitanian). The Eocene, Oligocene, and Miocene consist of limestones. The Pliocene consists of conglomerates, sandstones, clays, and marls. Oil indications occur in the Miocene.

The Loewoek embayment, along the south side of the East Arm of Celebes, consists of a generally homoclinal section 15 kilometers wide which flanks the Eocene limestone core of the peninsula. The Eocene limestones, about 1,000 meters thick, are overlain unconformably by 1,000 meters of older Miocene limestones. These in turn are overlain unconformably by 2,000 meters of Mio-Pliocene marls and sandstones succeeded by 1,500 meters of conglomerates and by 600 meters of Quaternary Reef limestones. An oil seep occurs near the base of the Miocene.

The Singkang embayment, 70–100 meters long and 40 kilometers wide, is located on the east side of the South Arm of Celebes. It is underlain by Pliocene conglomerates, sandstones, shales, marls, and limestones, estimated to be 2,500 meters thick, which lie unconformably on Miocene breccias, tuff-shales, and some fossiliferous limestones.

BOETON

This island, situated southeast of Celebes, is underlain by 2,500–3,500 meters of Miocene marls and limestones. Several large inliers of Eocene limestones and marls occur, also Cretaceous limestones, Jurassic limestones and marls, and Triassic dark gray shales, sandstones, bituminous limestones, and conglomerates. A major unconformity occurs at the base of the Miocene. The Miocene is overlain by 500–900 meters of Mio-Pliocene, foraminiferal marls and limestones.

The Triassic is intensely folded and faulted; the Jurassic is less intensely folded and faulted; and the Miocene and Pliocene are moderately folded.

Extensive asphalt deposits and tar seeps occur in the Miocene and Pliocene and a few light-oil seeps occur in the Triassic. The asphalt deposits, which consist of marls and soft limestones saturated with asphalt, are estimated to contain 80–100 million tons of asphalt rock ranging in bituminous content from 10 to 40 per cent, or an estimated 150–180 million barrels of asphalt.

TIMOR

A satisfactory report on the geology and the oil possibilities of Portuguese Timor is not available.

A number of oil indications occur in the Triassic, which includes marine sandstones, gray shales, and limestones, as well as dark, carbonaceous and bituminous shales. Permian and Jurassic marine strata also occur.

CERAM

Ceram consists largely of a complex of metamorphics, igneous rocks, and Jurassic and Triassic sediments. A few small embayments of Upper and Lower Tertiary strata occur, chiefly on the north coast. The Boela oil field, situated in the easternmost embayment, produced 7,500,000 barrels of petroleum from 1913 to the end of 1940.

NETHERLANDS NEW GUINEA

The Netherlands portion of New Guinea, having an area of about 153,000 square miles (nearly as large as California), may be divided geographically into three parts for discussion of the oil possibilities: (1) Vogelkop (Bird's Head), (2) North Coast or Mamberamo sector, and (3) South Coast or Merauke sector.

Vogelkop.—Stratigraphically and structurally the Vogelkop is the most attractive part of Netherlands New Guinea. The Tertiary section is thick and well exposed; numerous structures occur; and oil indications are present in several parts of the section. Exploration by drilling was barely begun before the Japanese invasion, and it will require years to explore fully the possibilities of various exposed structures and geophysical prospects.

The Tertiary in the Vogelkop includes thin Eocene and Oligocene limestones separated by a disconformity; 1,000–2,250 meters of Miocene limestones, shales, and marls; and 1,800–5,000 meters of Pliocene conglomeratic sands, shales, and marls with limestone lenses. The Pliocene deposits, which are both marine and terrestrial, lie conformably on the Miocene in some areas and disconformably on it in others. Pleistocene sands, clays, and lignites extensively conceal the structure in the Tertiary.

The Tertiary lies unconformably on either Mesozoic sediments or a complex of igneous and metamorphic rocks. The Mesozoic is made up of Cretaceous limestones, calcareous shales, and calcareous sandstones; and Jura-Cretaceous quartzites, shales, and slates. These two stratigraphic units are separated by an unconformity.

Oil indications occur in the Miocene and Pliocene and in the Cretaceous.

The presence of unconformities, disconformities, overlaps, and facies variations in the section, together with oil indications in the Cretaceous and in the Miocene and Pleiocene, places the region in a very favorable position with respect to trap possibilities.

A feature of great importance in the Vogelkop is the facies change involving

variation in porosity within the Miocene, which consists chiefly of marls, shales, reef limestones, and porous marly limestones. The oil accumulations found to date occur either in porous marls and marly limestones or in joints or fractures in dense limestones.

North Coast or Mamberamo sector.—This sector, which extends from Waropen Bay to the British New Guinea frontier, averages 55 kilometers in width. The basal unit of the Tertiary consists of 400–900 meters of Miocene globigerina marls, sandy marls, limestones, and conglomerates lying unconformably on a complex of metamorphics, igneous rocks, and Mesozoic sediments. The Miocene is overlain disconformably by 700–1,150 meters of Mio-Pliocene sandstones with thin clays, and these in turn are overlain conformably by 750 meters of Pliocene sandy clays, marls, sandstones and brown coals.

Oil and gas indications occur in the Miocene and Pliocene.

The North Coast has been explored only by reconnaissance surveys. The strata are rather strongly folded and faulted and the structures generally expose Miocene marls and sandstones.

South Coast or Merauke sector.—This sector extends from Etna Bay to the Papuan frontier and is believed to be similar in structure and stratigraphy to east Sumatra and the Barito Basin of south Borneo. The Central Mountains of New Guinea appear to form a borderland along an asymmetric basin of deposition hinged on the south on the foreland of Australia, now concealed by the Arafura Sea and alluvial deposits. Only a narrow belt of Tertiary strata is exposed along the Central Mountains. The greater part of the area is underlain by alluvium, which, in the Merauke area, forms a belt 250–300 kilometers wide.

BRITISH NEW GUINEA

The geology of British New Guinea is similar to that of Netherlands New Guinea, in that a central mountain range, made up of non-petroliferous Mesozoic and older rock complexes, is flanked on the north and the south by basins ranging in width from 40 to 100 kilometers.

The northern basin, which extends from the Huon Peninsula to the Netherlands New Guinea frontier, contains 4,000 meters of Miocene marine shales and sandstones, with thick limestone locally overlain unconformably by 2,500–5,000 meters of Pliocene marine and fresh-water shales, sandstones, and conglomerates. A disconformity is present locally within the upper part of the Miocene which lies unconformably on Eocene limestones, on Mesozoic sediments, or directly on a complex of metamorphics and igneous rocks. Oil indications are few and are restricted to the lower Miocene. The sedimentary basin, like many other basins in the East Indies, is asymmetric, and was hinged on a shelf-like area along the Central Mountains. In the late Miocene or early Pliocene a period of folding took place with considerable erosional truncation of the Miocene. This gave rise to more or less detached basins in which thick Pliocene deposits were laid down. While the coastal mountains may have been rising during much of the Pliocene, the main deformation of the basin took place at the end of the Pliocene.

This depositional basin has been broken into a number of topographic and structural units, as follows.

1. A relatively narrow coastal belt.

2. A chain of mountain ranges (or borderland) near the coast, which is interrupted by the valleys of the Sepik and Ramu rivers, where they flow north to the sea.

3. The great alluvial valleys of the Sepik, Ramu, and Markham rivers, which lie in a broad trough between the coastal ranges and the Central Mountains of New Guinea. This trough extends from Huon Gulf to the frontier and continues westward in Netherlands New Guinea as the alluvial valleys of the Idenberg and Rouffaer rivers. This trough is an important structural feature of northern New Guinea.

The Sepik-Ramu-Markham trough was depressed in the Pleistocene and since that time has been subject to extensive aggradation, which has partly concealed the Pliocene strata in the northern part of the trough and also the north flank of the Central Mountain complex. This terrestrial overlap within the island of New Guinea is similar to the terrestrial and marine overlap on the Malayan Shield in Borneo and Malaya and on the Australian Shield in southern New Guinea.

The eastern end of the northern basin has been folded into great geanticlines, namely, the Finisterre and Saruwaged ranges (up to 11,000 feet high) which form Huon Peninsula; and the Adelbert Range (5,000 feet elevation), west of Madang, which is an *en échelon* continuation of the Finisterre-Saruwaged uplift. Miocene strata, highly folded and even slightly metamorphosed, form the cores of these geanticlines, with much folded and faulted Pliocene strata on the flanks of the uplift.

The Sepik-Ramu trough extends from the Huon Gulf, west to the Netherlands New Guinea frontier. The northern side of the trough, that is, along the south side of the coastal ranges, is underlain by Pliocene strata which rest unconformably on folded Miocene sediments. In the central part and along the southern side of the trough, shelf-like conditions apparently prevailed through the Miocene and Pliocene. There the section is thinner and folding is more gentle or absent, following the pattern of similar asymmetric basins in the East Indies.

Oil odors and some gas seeps occur in the folded Pliocene and Miocene.

The coastal ranges, west of the Sepik River, include the Bewani and Torricelli mountains (up to 6,000 feet) which expose rocks of the pre-Tertiary basement complex.

The very minor coastal lowlands east of the Ramu River are essentially part of the north flank of the Adelbert and Finisterre geanticlines. West of Matapau, however, the coastal lowlands widen and coincide with the Bewani geosyncline which widens still further west toward the Netherlands New Guinea frontier. This geosyncline is the eastward extension of the Mamberamo Basin in Netherlands New Guinea, where a number of gas seeps and a few oil seeps are reported. In the Bewani geosyncline of British New Guinea oil seeps occur at Matapau and a number of gas seeps and rocks with oil odor are reported at the west.

The Tertiary geosyncline in Papua (southern British New Guinea) is an extension of that in Netherlands New Guinea and, like it, is an asymmetric basin of deposition, with steep folding on the northeast along the Central Ranges where the section is very thick, and with more gentle folding on the southwest, where the basin is hinged on the Australian Shield and the section is thin.

The Tertiary consists chiefly of Miocene strata, 2,000–5,000 meters thick and about 2,000 meters of Pliocene sediments. The Miocene is largely marine and consists of graywackes, tuffaceous sandstones, mudstones, and shales in the deeper part of the basin, and limestones in the stable shelf area on the south. The Pliocene includes marine and terrestrial sediments and consists of sandstones, sandy shales, conglomerates, agglomerates, and tuff sands. The Miocene lies unconformably on a complex which includes Jurassic and Cretaceous marine limestones, shales, sandstones and conglomerates and locally Eocene silicious shales, limestones, and grits. A disconformity is present between the Miocene and Pliocene in some areas. This part of New Guinea was subjected to extensive volcanism in the Upper Tertiary and Quaternary and the southern basin, therefore, contains great amounts of tuffaceous deposits and, locally, agglomerates, and lava flows.

Many oil and gas indications occur, but they are restricted chiefly to that area where the basin swings southerly along the Oriomo-Kikori spur of the Australian Shield. This seepage area also coincides with the part of the geosyncline which probably had a trough-like connection in the lower and middle Miocene with the northern basin, across what is now the Central Mountains. The source of the oil, as elsewhere in New Guinea, appears to lie in the lower and middle Miocene. These formations, however, are thin and consist chiefly of limestones on the shelf area around the Australian Shield, where oil indications are generally absent. The marine shales occur chiefly in the Aure trough area, east and northeast of the shield, but even in this area, the Miocene includes many thick tuffaceous sandstones and graywackes.

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TUPUNGATO OIL FIELD, MENDOZA, ARGENTINA[1]

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ABSTRACT

The Tupungato oil field is 50 kilometers south-southwest of the city of Mendoza in west-central Argentina, in an area just east of the foothills of the Andes Mountains where the principal tectonic features are overthrust faults of late Tertiary age. The surface structure, discovered in 1932, is a closed dome with faulted west flank. The discovery well was completed in 1934 at a depth of 250 meters. Seventeen shallow wells were drilled to depths averaging 450 meters, most of which produced oil with strong flows of salt water from fractures in the upper part of the Tertiary (Pliocene) section. The discovery well of the Victor zone of Upper Triassic age was completed in 1938 at a depth of 1,796 meters. The peak production from this zone, 9,400 barrels per day, was reached in October, 1941, after the completion of 17 productive wells.

The major part of the difference between the structure of the surface and that of the various horizons which can be identified in well samples is believed by the writer to be due to the presence of low-angle thrust faults which cause variations in the thickness of the Tertiary section in different parts of the field, but this can not be definitely proved. There is some indication of the existence of a gentle fold prior to the deposition of the Tertiary.

The oil of the Victor zone occurs in fractures and pores of the upper part of a thick series of volcanic tuffs, but is believed to be produced almost entirely from the fractures. It is of the same type, with a high paraffine content, as that produced from lower stratigraphic levels in the other oil fields of northern Mendoza.

A deeper zone, probably of little importance, was opened by the completion of T 48 in July, 1942, at 2,563 meters. In December, 1942, well T 50 reached the zone which is productive in the Cacheuta and Lunlunta fields, finding a higher-grade oil under high pressure but with small volume. At that time, it was the deepest well in Argentina, 2,921 meters. The importance of this discovery must be determined by future drilling.

The Yacimientos Petroliferos Fiscales is the sole operator.

INTRODUCTION

The Tupungato oil field has played an important part in the efforts of the Yacimientos Petroliferos Fiscales, the Argentina Government oil company, to make that country independent of foreign oil supplies. In 1938, Argentina produced 2,714,824 cubic meters (16,300,000 barrels) of crude oil, placing it eleventh in rank among the oil-producing countries of the world. In 1941, its production amounted to 3,499,757 cubic meters (22,000,000 barrels), an increase of 29 per cent over that of 1938, to which the Tupungato field contributed 464,755 cubic meters (2,900,000 barrels), or 13 per cent of the total, thereby making it one of the most important fields. In addition to its economic importance, it presents a number of features of geologic interest, which is the justification for the presentation of this paper.

The writer alone is responsible for the conclusions herein presented, but these are based entirely on the work of others. Full acknowledgment is therefore made to the authors cited in the text and to those geologists of the YPF[3] whose unpublished reports have furnished the data which have made possible its prepara-

[1] Presented by title before the Association at Denver, April 22-24, 1942. Manuscript received, June 12, 1944. Published by permission of Yacimientos Petroliferos Fiscales: *Bol. Informaciónes Petroleras*, Ano XXI, No. 237 (Buenos Aires, Mayo de 1944), pp. 7-27.

[2] Phillips Petroleum Company.

[3] In general use as an abbreviation for Yacimientos Petroliferos Fiscales.

tion. Particular mention should be made of the work of Richard Stappenbeck, Eduardo Trumpy, C. I. de Ferrariis, and O. I. Bracaccini on the surface geology, that of J. C. Yussen de Campana and Eduardo Trumpy on the stratigraphy, and that of J. C. Yussen de Campana and A. H. Richards on the well samples and their correlation.

LOCATION

The Tupungato oil field is 50 kilometers south-southwest of the city of Mendoza, the capital of the province of the same name in west-central Argentina, and approximately 1,000 kilometers by railroad from Buenos Aires. It may be reached by highway from Mendoza, a distance of about 60 kilometers.

Being located in the area just east of the foothills of the Andes Mountains, it has the arid climate characteristic of that zone, with an average annual rainfall of only 6 inches. There are no permanent streams in or near the field, and water for drilling is brought by pipeline from a stream 13 kilometers southwest. The average elevation is 1,200 meters above sea-level, with a relief of 60 meters within the productive limits of the field. The surface is dissected by many ravines which make the construction of roads and drilling sites somewhat difficult.

HISTORY[4]

The presence of impregnations of asphalt in the sandstones which crop out at the foot of the south slope of Cerro Cacheuta, 70 kilometers southwest of the city of Mendoza, has been known for many years. The first geological description was given in 1873 by Stelzner[5] in his work on the geology of Argentina.

In 1886, the Compañia Mendocina de Petroleo was formed to exploit these deposits and search for a possible oil field. Following a geological study by Rudolph Zuber,[6] four wells were drilled down the dip from the outcrops, of which three were productive of oil. Twenty-two wells with a maximum depth of 280 meters were drilled by this company in a period of 4 years. Well No. 7 is said to have produced 40 cubic meters (250 barrels) per day initially by natural flow. A $3\frac{1}{2}$-inch pipeline was laid to Godoy Cruz, a distance of 35 kilometers. However, production declined rapidly, and operations were suspended in 1897.

In 1909, the Argentine Petroleum Syndicate drilled three wells farther south, but became discouraged when oil was not found at the expected shallow depth. The Cacheuta Oil Syndicate was later formed and drilled two wells, one of which, the Victor, was productive in the beds above the bituminous shales which overlie the oil-bearing sands at the outcrop. The operations of this company were suspended in 1914 because of financial troubles and the outbreak of the European war.

[4] The early history has been taken from E. Fossa-Mancini, "Cómo descubrió YPF petróleo en Tupungato," *Boletín de Informaciónes Petroleras 124* (Buenos Aires, December, 1934).

[5] R. Stelzner, "Geología de la República Argentina," *Actas Academia Nacional de Ciencias de Córdoba*, Tomo VIII (1875).

[6] R. Zuber, "Estudio Geológico del Cerro Cacheuta," *Academia Nacional de Ciencias de Córdoba*, Tomo X (1887).

In 1926, Guido Bonarelli made a geological report for the YPF, in which he recommended exploration of the area as far south as the Rio Tunuyan because of the presence of favorable surface structures, although he thought that the depths to the probable oil zones might be difficult to reach with wells. Other studies begun by the YPF at this time were discontinued because of the greater interest in the Comodoro Rivadavia and Plaza Huincul fields.

The YPF made a further study of the Cacheuta field in 1930 at the request of the government of the province of Mendoza, as a result of which Enrique Fossa-Mancini[7] made a new and different interpretation of its structure and recommended further drilling. This company then acquired the rights of the former companies and began development the following year.

On February 13, 1931, the YPF was granted the exclusive right to explore for oil within the province of Mendoza for a period of 5 years, which was increased to 10 years the following year. Accordingly, Richard Stappenbeck, who had formerly studied this area for the Dirección General de Minas, was commissioned to make a reconnaissance survey of the region. His report,[8] presented in 1933, showed the presence of an anticlinal structure which extends south-southeast from the Cacheuta field to the Rio Tunuyan, on which there are a number of subsidiary closed highs, including that of the Tupungato structure. He also discovered the long anticline 25 kilometers east on which the Lunlunta and Barrancas fields were later discovered.

The first well on the Tupungato structure was begun in March, 1934, located on the highest part of the surface structure, approximately 25 kilometers south of the outcrops of the oil sands at Cacheuta. Showings of oil were found at 225 meters, and an oil sand from 248.5 to 252.5 meters, which produced initially at the rate of 10 cubic meters (63 barrels) per day. Seventeen wells were subsequently drilled to depths between 400 and 550 meters, nearly all of which found oil accompanied by strong flows of salt water at varying stratigraphic levels. To the middle of 1941, when the last of these wells was shut in, 10,000 cubic meters (63,000 barrels) of oil had been obtained, most of it having been produced with flowing salt water. The best well, T 8, recovered 2,275 cubic meters (14,300 barrels). The oil was similar to that of the Cacheuta field, with an average specific gravity of 0.88 (29.5° API), and a very high viscosity at average atmospheric temperature.

It was soon recognized that the shallow production was relatively unimportant, and that the chief prospects of the structure lay in the possibilities of deeper production from the sands of the Potrerillos formation which produce the major part of the oil at Cacheuta, and which were then estimated to lie at depths of 1,500 meters or more. Accordingly, well T 10 was begun as a deep test in December, 1935, at a location near the surface axis and 1,800 meters northeast of the discovery well T 1. After reaching the depth of 1,667 meters, failure to recover stuck tools forced the abandonment of this well.

[7] E. Fossa-Mancini, *op. cit.*

[8] Unpublished report of the YPF.

The next attempt to reach the deeper zone was begun in December, 1937, with well T 19, a short distance east of T 10. After much difficulty in penetrating several zones with large flows of water under abnormally high pressure, $9\frac{5}{8}$-inch casing was cemented at 1,662 meters, and drilling continued. A showing of gas was noted at 1,730 meters in the top of the Victor, but was proved unproductive by a test. Showings of oil were found at 1,769 meters. While coring at 1,796 meters, the well blew out and caught fire on July 22, 1938. The fire was extinguished 2 days later, and the well put on production through the drill pipe which remained in the hole, giving an initial production of approximately 400 cubic meters (2,500 barrels) per day. Development of this zone, known as the Dark Victor, followed as rapidly as possible in view of the difficulties in drilling through the high-pressure water zones. The peak production of 1,490 cubic meters (9,400 barrels) per day was reached in October, 1941, from 17 wells. By August, 1942, 26 wells had been drilled to this zone, of which 24 were productive.

The finding of oil in the beds of the Victor group was not expected, since this formation was not believed to contain permeable beds. Deeper testing was therefore planned as soon as the subsurface structure had been outlined. Accordingly, well T 48 was begun in August 1941, at a location slightly east of the subsurface high in the Victor. Showings of oil were found in sandstones and conglomerates below 2,420 meters, and a string of 7-inch casing was cemented at that depth to test them. As a production test of the section between 2,420 and 2,458 meters gave only 3 cubic meters per day, drilling was continued. At 2,559 meters it was found impossible to keep mud in the hole because of the high pressure. However, a test showed that although the pressure was in excess of 400 atmospheres, the permeability was so low that only 10 cubic meters per day was produced by intermittent flow. Deepening by 4 meters did not increase the rate of production.

The presence of steeply dipping beds in the lower part of well T 48 indicated that it had probably passed from the gentle east flank to the steep west flank of the structure, and that it would be impracticable to attempt to reach lower horizons at that location. A new deep test, T 50, was therefore begun in December, 1941, at a location 550 meters east. This well found a much greater thickness of the lower formations than was known in the other fields of the province of Mendoza. Only small showings were found in that part of the section which was productive in T 48. The top of the Potrerillos, the oil-producing formation of the Cacheuta and Lunlunta fields, was found at 2,899 meters. At a depth of 2,905 meters, it became impossible to control the pressure, and the well flowed a small amount of oil of a light color and different characteristics from those of the shallower formations. Technical difficulties made it necessary to drill a new hole below the shoe of the 7-inch casing, which had previously been cemented at 2,286 meters. A string of $5\frac{1}{2}$-inch casing was cemented at 2,870 meters, and drilling continued to 2,921 meters, or 18 meters below the top of the Potrerillos as found in the second hole. A production test after lowering a perforated liner gave an average of 10.7 cubic meters per day for 7 days. Since it was found impossible to re-

move the liner, the well was completed at that depth (9,583 feet), making it the deepest well drilled in Argentina at that time. (This depth has since been exceeded by well TR 2 in the neighboring Refugio field, which was drilled to 3,216 meters (10,551 feet).)

Two wells, T 51 and T 58, are now being drilled to test the importance of the Potrerillos formation.

STRATIGRAPHY

The following description of the stratigraphy has been prepared with the collaboration of J. C. Yussen de Campana, and is based on her examination of well samples and the work of various geologists on the surface outcrops. The nomenclature is that in current use by the geologists of the YPF, although it differs somewhat from that adopted by them in 1938[9] to replace that presented in 1917 by Stappenbeck.[10]

QUATERNARY

The alluvium and river gravels found bordering all of the larger streams and dry courses, the alluvial fans at the mouths of the canyons of the foothills, and the windblown sands are classed as Recent in age. They cover a relatively large part of the surrounding area and completely obscure the structure of the underlying formations. They rest unconformably on a rough surface and have a highly variable thickness. Some deposits of loess which cover a large area near Borbollon, north of Mendoza, are also believed to be Quaternary in age, although they have inclinations of the bedding planes up to several degrees which are apparently due to folding. Trumpy[11] reports a number of localities in which folding of Quaternary beds is present.

An angular unconformity of great magnitude marks the base of the Quaternary.

TERTIARY

(POSSIBLY INCLUDING SOME PLEISTOCENE)

The sediments which lie below the aforementioned unconformity and which are of undoubted Tertiary or younger age reach thicknesses of at least 3,000 meters. They are characterized by very poor sorting and stratification, the presence of many conglomerates which are principally composed of more or less rounded pebbles and boulders of andesite of earlier Tertiary age, and by a large percentage of volcanic material such as tuffs, ashes and lapilli. A number of unconformities have been reported within this series, but it is difficult to determine their importance and to judge whether they have been caused by folding and erosion or merely represent local breaks in the sedimentation.

[9] E. Fossa-Mancini, E. Feruglio, and J. C. Yussen de Campana, "Una Reunión de Geólogos de YPF y el Problema de la Terminología Estratigráfica," *Boletín de Informaciónes Petroleras 171* (Buenos Aires, November, 1938).

[10] R. Stappenbeck, "Geología de la Falda Oriental de la Cordillera del Plata," *Anal. Ministerio de Agricultura,* Tomo XII (Buenos Aires, 1917).

[11] Unpublished reports of the YPF.

The subdivisions of this section are the result of studies of the outcrops and well samples by various geologists of the YPF over a period of 10 years. They give a classification which is fairly satisfactory, considering the nature of the sediments and the lateral lithologic variations, for both outcrops and wells.

The beds above the unconformity at the base of the Lower Gray tuffs have been classed as Pliocene by Rovereto,[12] on the basis of vertebrate fossils. No fossils have been reported from the Mariño, below this unconformity, and its age is not definitely known, but is believed to be Miocene.

Mogotes conglomerate.—This is a series of poorly assorted conglomerates with interbedded sandstones and shales whose thickness may exceed 1,000 meters. The conglomerates are composed of rounded pebbles and boulders of a large variety of crystalline rocks, among which are Tertiary andesite, Triassic lavas, Paleozoic granites, porphyries, and other igneous and metamorphic rocks. Its upper part may be Pleistocene in age.

Yellow series.—This group is made up of shales, sandstones, and conglomerates of a light yellow color, which grade upward into the Mogotes conglomerate without any abrupt change. It crops out on the flanks of the Tupungato structure, where its thickness is approximately 400 meters, and it rests on the Upper Gray tuffs with an irregular surface of contact.

Erosional unconformity of unknown magnitude.—This unconformity has been used as the dividing line between the "Upper" and "Lower" Tertiary in Figure 1, not because it is believed to be of great importance, but to give a better representation of the structure by the areal geology.

Upper Gray tuffs.—This series is chiefly composed of light gray sandy volcanic tuffs, with lapilli and interbedded conglomerates. Its outcrop encircles the Tupungato structure, where it has a thickness of approximately 200 meters. These tuffs may be recognized over a large area and are therefore of great assistance in geologic mapping. Their base has been used as the key horizon for the surface structural map of Tupungato (Fig. 3). They are not definitely recognizable at Lunlunta or Barrancas, but a zone which contains a relatively high proportion of volcanic material is probably their equivalent.

La Pilona.—This group of shales, sandstones and conglomerates, with much volcanic material, crops out in the center of the Tupungato structure. Its average thickness in the wells is 550 meters, but a greater thickness is probably present in the outcrops on the north.

Lower Gray tuffs.—These are gray volcanic tuffs, similar to those above the La Pilona, with tuffaceous sandstones and red shales. They are found both on the surface south of Cacheuta and in the wells at Tupungato, where they have an average thickness of 200 meters. They are the first marker to be noted in the well samples. They are not recognizable in the wells at Lunlunta and Barrancas.

Mariño.—Red shales, green, gray, and red sandstones and conglomerates

[12] C. Rovereto, "Los Estratos Araucanos y sus Fósiles," *Anales del Museo Nacional de Historia Natural,* Tomo XXV (Buenos Aires, 1914), pp. 1–247.

form this division, with 70–100 meters of highly cross-bedded sandstone of aeolian deposition as its basal member. Its average thickness in the wells at Tupungato is 900 meters, but varies greatly, the possible explanation of which is discussed

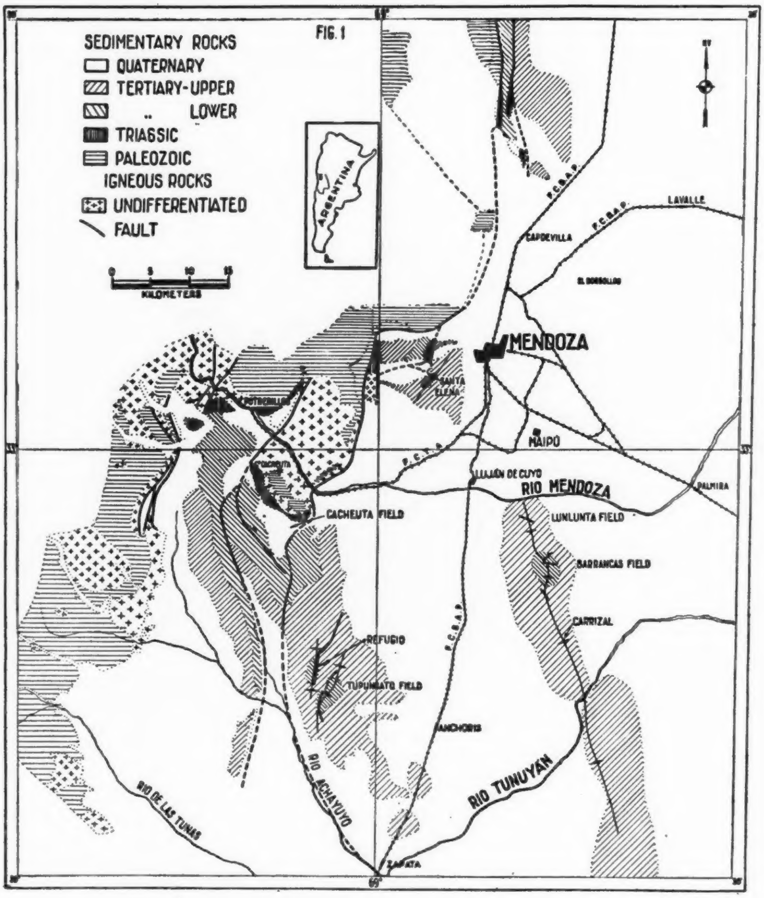

FIG. 1.—Areal geology of part of province of Mendoza, showing relation of Tupungato field to general structure. Width of area mapped, 93 kilometers (58 miles).

later. It is considerably thicker in Lunlunta and Barrancas, reaching 1,300 meters, with 150 meters of the basal cross-bedded sandstone.

Violet conglomerate.—This is a section which averages 50 meters in thickness, but varies widely from that figure, composed of a violet conglomeratic sandstone

containing small pebbles of crystalline rocks, including andesite of Tertiary age, with interbedded violet marl. It grades upward into the overlying sandstones in the Lunlunta and Barrancas fields. It has been found in all wells in the northern Mendoza fields. Its base is the first marker which may be depended on to show the approximate structure of the underlying formations, although it undoubtedly marks the presence of an important unconformity and there are large variations in the interval between it and lower markers. The Violet conglomerate was included in the "Cretaceous" of Stappenbeck.

An angular unconformity separates the Tertiary and the Triassic.

UPPER TRIASSIC?

Variegated shales.—These vari-colored shales with interbedded tuffs, whose thickness varies from 15 to 50 meters, have been recognized in outcrops and in all wells with the exception of LC 1 on the Carrizal structure. It contains beds of dark bituminous shale with plant remains in the Lunlunta-Barrancas area.

Anhydrite zone.—This is a series of dark red shales with veins and nodules of anhydrite or gypsum, but with no volcanic material, which is found in outcrops near Cerro Cacheuta and also in wells at Cacheuta, Lunlunta, and Barrancas. It may also be present with a reduced thickness at Tupungato, but it has not been separated from the Variegated shales.

Red conglomerate.—This is a conglomeratic sandstone to conglomerate of a dark red color, containing pebbles of quartz and crystalline rocks, known in some outcrops and in all wells with the exception of those in the Cacheuta field. Its thickness is variable, up to 100 meters or more. Its base is a definite marker, and, although it may mark the presence of an important unconformity, is of value to indicate the approximate structure of the deeper beds.

The Variegated shales, Anhydrite zone, Red conglomerate, and the Light Victor were included with the Violet conglomerate in the "Cretaceous" of Stappenbeck. Trumpy and Yussen de Campana[13] consider the base of the Violet comglomerate as the base of the Tertiary of northern Mendoza, and include the Variegated shales in the Upper Triassic on the basis of the fossil plants found therein.

Unconformity of unknown magnitude.—The presence of 63 meters of fine-grained very micaceous sandstone in the well LC 1 at Carrizal, and its absence in all other wells, suggests that this unconformity may be of importance in some areas.

The name Victor has been applied to a series composed mostly of volcanic tuffs with some interbedded shales and sandstones that is only partly known from outcrops. It has been subdivided on the basis of well samples into the Light, Dark, and Gray Victor. The thicknesses of each division and that of the whole group vary greatly from one field to another, and the Dark Victor has not been recognized in Lunlunta or Barrancas. The Tupungato section is as follows.

Light Victor.—These hard tuffs with minor shales and sandstones vary in

[13] Unpublished reports of the YPF.

thickness from 11 to 29 meters in all wells with the exception of T 27 and T 29, both of which are located on the steep west flank, where thicknesses of 126 and 47 meters, respectively, were found, a part of which is due to the high inclination of the beds. It is highly fractured and contains oil residues, quartz, chalcedony, and zeolites in the fractures. It is present with a greater thickness in wells at Cacheuta, Lunlunta, and Barrancas.

Dark Victor.—This is the oil-producing formation of the Tupungato field. It consists of approximately 300 meters of hard volcanic tuffs of dark green, gray, and violet color, with interbedded shales. Material formerly classified as sandstone has been shown by Yussen de Campana[14] to be composed of crystals of analcite which have been derived from the tuffs by alteration. The distribution of these "sandstones" varies greatly from well to well, and they contain varying saturations of oil. Although their porosity is high, they have an extremely low permeability. Small pores of irregular shape, apparently formed by solution, have been noted in cores and samples throughout the Dark Victor. These beds have been intensely fractured, and cores show that those openings that have not been filled with calcite or zeolites contain oil.

The full thickness of 300 meters has been penetrated by only 6 wells in the Tupungato field. In the Refugio field, 4 kilometers northwest of Tupungato, only 230 meters is present. It has not been identified in the Cacheuta, Lunlunta, or Barrancas fields.

Gray Victor.—This group has been completely penetrated by only two wells in Tupungato, T 50 and T 58, which found thicknesses of 472 and 468 meters, respectively. These probably represent the true thickness, since the maximum dip observed was 15°, and the average much less. The thickness at Refugio is 285 meters. It is also known in the other fields of northern Mendoza, with thicknesses which vary widely within short distances, but are generally less than 100 meters.

It has been divided into two parts, the upper, which consists of gray shales and micaceous sandstones, and the lower, which in addition to the shales and sandstones contains conglomerates and black bituminous shales which are similar to and easily confused with those of the underlying Cacheuta. These shales have a thickness of 64 meters, in T 48, and were believed to be the Cacheuta until well T 50 was drilled.

Well T 48 produces a small amount of oil from the Lower Gray Victor, but it is improbable that this zone will be found to be of much importance since only small showings were noted in T 50.

Cacheuta shale.—The black bituminous shales of the Cacheuta are well known from various outcrops in northern Mendoza. From their fossil content of plants, fish scales, and *Estheria* they have been placed as Rhaetic or Upper Triassic in age.[15] Its thickness averages 100, 130, 70, and 80 meters, respectively, in the

[14] Unpublished reports of the YPF. See also W. H. Bradley," Zeolite Beds in the Green River Formation," *Science*, Vol. 67 (1928).

[15] For a discussion of the evidence for the Triassic age of the Cacheuta shale and references, see H. L. Harrington, "Investigaciones Geológicas en las Sierras de Villavicencio y Mal País," *Ministerio de Agricultura, Dirección de Minas y Geología, Boletín 49* (Buenos Aires, 1941), pp. 25–27.

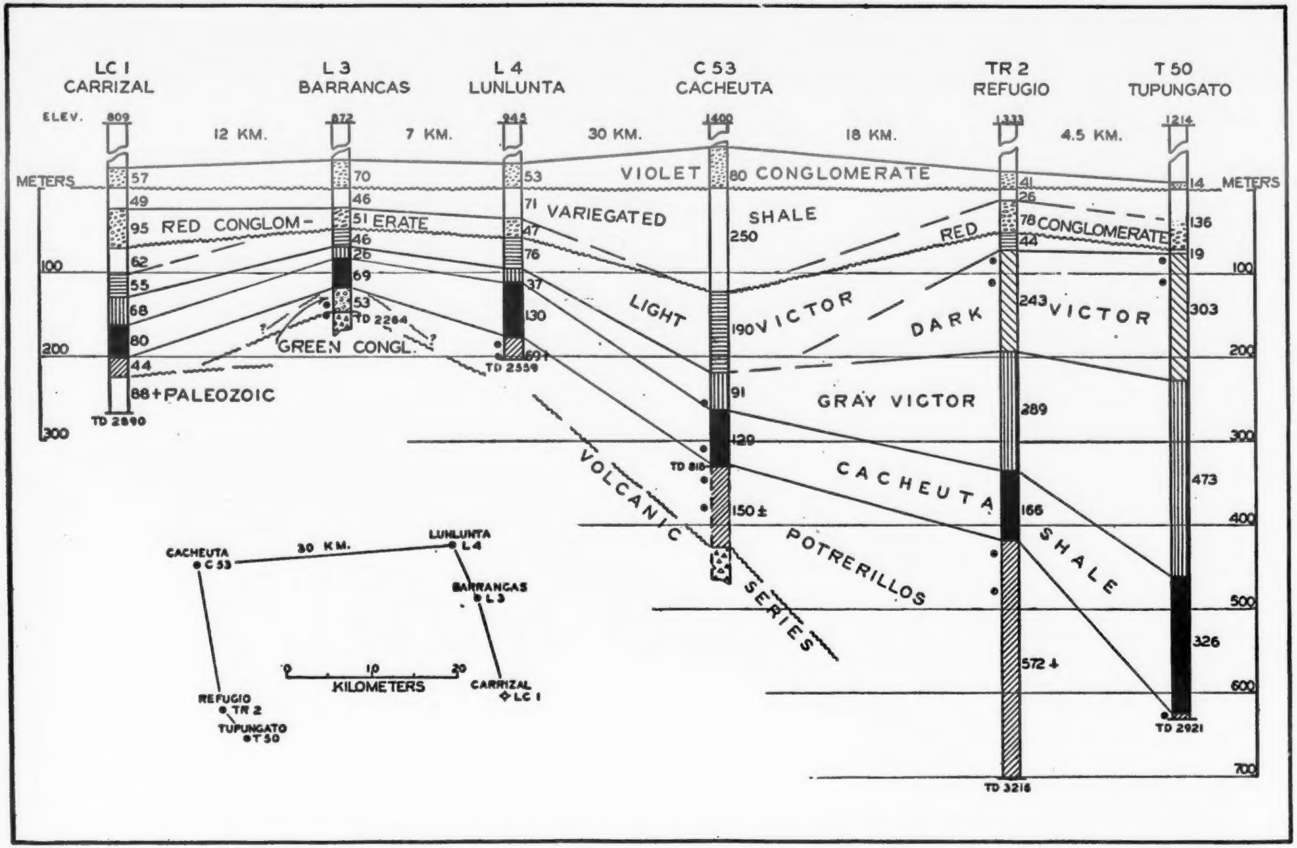

FIG. 2.—Correlations of pre-Tertiary section between oil fields of northern Mendoza. Wells are aligned on base of Violet conglomerate, base of Tertiary.

Cacheuta, Lunlunta, Barrancas, and Carrizal wells. A thickness of 166 meters is present at Refugio, while T 50, the only well in the Tupungato field which has completely drilled this formation, and which is only $4\frac{1}{2}$ kilometers from Refugio, found 326 meters. The oil of northern Mendoza is believed by some geologists to have originated in the Cacheuta shale.

Potrerillos.—Sandstones, conglomerates, shales, and tuffs, with much volcanic material throughout, make up this group which is well known from its outcrops. It also contains some bituminous shales with plant remains, also beds of bentonite which are mined for use in drilling mud. It has a great lateral lithologic variation as well as range in thickness. Its sandstones, although of low average permeability due to their tuffaceous character, produce oil in the Cacheuta and Lunlunta fields, and have been shown to contain oil in the Tupungato field by well T 50, although their importance has not yet been definitely proved.

The Potrerillos is missing, probably from non-deposition, in the structurally high wells in the Barrancas field, but reaches a thickness of 50 meters on the flanks. In the Lunlunta field, 90 meters has been drilled without reaching its base. Its thickness in the Cacheuta field is variable, as it rests on the weathered surface of the Triassic lava flows, but the maximum known is 240 meters. A thickness of 572 meters was drilled in well TR 2 at Refugio without reaching its base, and its thickness at Tupungato is probably of the same order. At the type locality of Potrerillos, 15 kilometers west of Cerro Cacheuta, a thick series of red conglomerates is present between the typical Potrerillos and the lava flows.

Green conglomerate.—This is known only in wells of the Barrancas field, where it consists of 40 meters of a conglomerate of fragments of green volcanic tuffs with some sandstones, probably derived from the weathering of the underlying volcanic series. A part of the oil of the Barrancas field is produced from this formation. It may or may not be present in the Lunlunta and Tupungato fields.

An unconformity separates the Upper and Lower Triassic.

LOWER TRIASSIC

Volcanic series.—This series of rhyolite flows and interbedded tuffs crops out at Cerro Cacheuta, and has been found in some of the wells in the Barrancas field, where its weathered and fractured upper part contains oil. Its thickness and areal distribution are discussed under Geologic History.

Although sediments of Paleozoic age are known to exist below these flows in some parts of northern Mendoza, they are not discussed since they are probably beyond the reach of the drill in the Tupungato field.

Figure 2 shows the correlations of the pre-Tertiary section between the five producing oil fields of northern Mendoza and the well LC 1 at Carrizal.

STRUCTURE

GENERAL STRUCTURE OF REGION

Figure 1, which is a compilation of a number of unpublished maps of the YPF, is presented to show the principal geologic features of the region by means

of the areal geology.[16] In order to avoid the inclusion of details which would not add to its value for this purpose, a number of formations have been grouped together, as follows.

No distinction has been made between the various types of Quaternary deposits.

The Tertiary has been divided into two parts, so selected as to best show the general structure. The upper division includes the Mogotes conglomerate and the Yellow series, and the lower division consists of the remaining beds down to the base of the Violet conglomerate.

All beds from the base of the Violet conglomerate down to the top of the Triassic lava flows have been grouped as "Upper Triassic."

All sediments below the Triassic lava flows have been grouped together as "Paleozoic sediments." Some of these are highly metamorphosed, having been subjected to intensive deformation prior to the Mesozoic.

No distinction has been made between the Tertiary flows and intrusions, the Triassic flows, and the Paleozoic and older igneous rocks, all of which have been included as "Igneous rocks."

The metamorphosed sediments and igneous rocks form the foothills of the Andes Mountains which rise abruptly above the general level of the areas covered by the younger rocks. It is believed that their outcrops are everywhere limited on the east by thrust faults, which cause them to overlie younger formations, as there is no case known to the writer where a normal sequence from the Tertiary down to the Paleozoic may be seen in a section from east to west.

These thrust faults are the principal tectonic features, and the major ones are shown in Figure 1. They were undoubtedly formed by compressive stresses from the west during the late Tertiary or early Quaternary. Their irregular traces on the surface suggest that they may have rather low angles of inclination with the horizontal. The common occurrence of crystalline rocks of Paleozoic age resting on high levels of the Tertiary section shows that the vertical components of the displacement of the larger of these faults must be measured in thousands of meters, with the possibility that their horizontal components are of the order of 5 kilometers or more. Such overthrusts are characteristic of the foothills of the Andes and the area adjacent on the east, from the province of Mendoza northward. However, Harrington[17] reports that the planes of the faults in the Villavicencio area, 80 kilometers north, are apparently nearly vertical. The magnitude of those faults which extend into the area of Tertiary outcrops apparently decreases southward.

In addition to the major faults, there are innumerable smaller ones which cut

[16] For a small-scale geological map of the province of Mendoza and a discussion of the general stratigraphy, see P. Groeber, "Mapa Geológico de Mendoza," *Physis*, Tomo XIV (Buenos Aires, 1939), pp. 171–220.

[17] H. L. Harrington, *op. cit.*, p. 31.

the Tertiary outcrops in an apparently erratic manner. However, all of them are believed to be subsidiary to the major faulting, and many of them are probably superficial in character, and of little importance in connection with the subsurface structure.

The areal geology of Figure 1, together with dips in the Tertiary beds, indicate the presence of two major lines of folding. The best developed is the long anticline in the eastern part of the area, which may be traced for many kilometers southward from the Rio Mendoza, and on which the Lunlunta and Barrancas oil fields are located. While many faults have been found along this anticline, none of them can be considered of major importance with reference to the regional structure.

The other line of folding, which extends from Cerro Cacheuta to Tupungato and probably still farther south, is complicated by the presence of thrust faults which cut across its general trend, so that it is not a simple anticline. The Tupungato field is located on one of several surface highs found along this line of folding.

Both of these major folds are believed by the writer to have been formed by the same compressive stresses which caused the faulting, although they may have been localized by the presence of earlier folding in the pre-Tertiary formations.

SURFACE STRUCTURE OF TUPUNGATO FIELD

The surface structure of the Tupungato field is shown by Figure 3, which is a compilation from three maps of the YPF, one made by Eduardo Trumpy in 1936 which shows the areal geology, faults, dips and strikes, and outcrops of oil saturated sandstones near the center of the fold (not shown in Figure 3), that made by C. I. de Ferrariis in 1938, which represents the structure by contours on the base of the Upper Gray tuffs, and a map of the extreme south end by O. I. Braccacini in 1940. It shows the presence of a domal structure with a faulted west flank, with a closure of approximately 250 meters. The principal fault on the west flank is an overthrust from the west, whose vertical component increases from 10 to 20 meters on the north end of the area mapped to about 200 meters on the south end. Although this and the other subsidiary faults are important in the surface structure, it is the writer's opinion that their planes of fracture approach parallelism with the bedding with increasing depth, as shown by the cross section of Figure 8, and that they do not affect the deep structure in the immediate vicinity of the field. However, this opinion is not shared by others, and no information is available either to prove or disprove this interpretation. Many small faults with no apparent regularity in their distribution cut the surface beds in all parts of the structure. Not all of them are shown in Figure 3.

The location of both the shallow and the deep wells with respect to the surface structure is also shown in Figure 3.

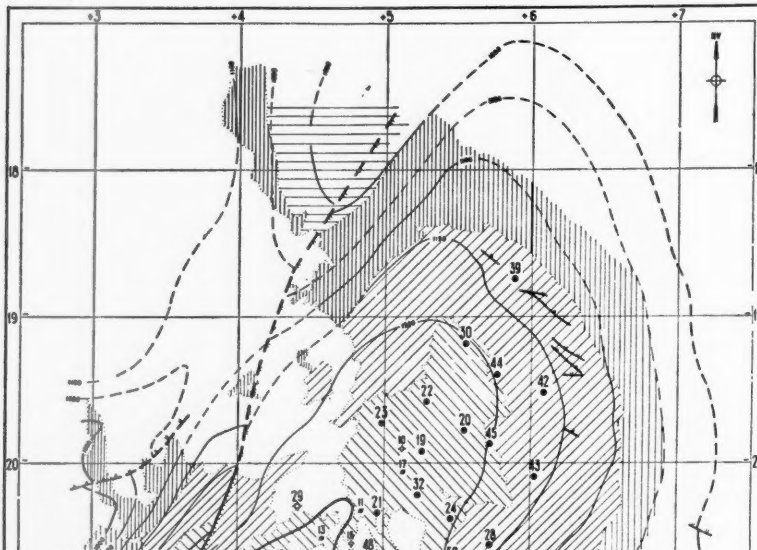

FIG. 3.—Areal geology and surface structure of Tupungato field. Contours on base of Upper Gray tuffs, interval 50 meters. Coördinate lines at 1-kilometer intervals.

SUBSURFACE STRUCTURE

All interpretations of the subsurface structure of the various horizons are based on well sample determinations and are subject to varying degrees of error

TABLE I

WELL DATA

(Meters, referred to sea-level)

No.	*Comp.*	*TLGT*	*BVC*	*BRC*	*TDV*	*Pen.*	*IP*	*Recov.*	*Remarks*
19	7/38	661	−429	−529	−558	38	400	181,120	Discovery well, Victor zone
20	5/39	654	−416	−567	−582	227	130	62,808	Pumping, 0–5% water
21	8/39	699	−395	−501	−526	153	250	208,158	
22	11/39	632	−412	−553	−562	264	362	331,068	229 M³/day, 13% water
23	12/39	701	−459	−642	−665	274	50	11,008	Pumping 6 M³, 10–40% water. 3% water initially
24	3/40	692	−420	−557	−570	407°	80	45,085	Drilled all of Dark Victor
25	5/40	690	−427	−545	−570	125	350	121,496	
27	Susp.	699	−549	−654	−780	146	—	—	Low on west flank
28	1/41	598	−463	−612	−623	110	130	50,963	
29	Susp.	697	−662	−815	−862	114	—	—	Low on west flank
30	10/40	699	−423	−575	−592	268	192	69,292	Pumping
31	11/40	681	−414	−557	−573	350°	15	6,116	Top Gray Victor −866
32	1/41	698	−396	−532	−549	201	90	29,903	
33	1/42	711	−400	−537	−551	250	5	963	
35	8/41	601	−503	−661	−674	115	5	746	Pumping
36	3/41	697	−363	−508	−523	121	70	19,855	
37	5/41	684	−458	−608	−622	417°	43	13,806	Top Gray Victor −974?
39	5/41	617	−491	−654	−672	158	20	5,207	Pumping
41	5/42	660	−553	−673	−707	259	12	3,101	Pumping, little water
42	5/41	600	−464	−635	−653	90	160	45,635	
43	12/41	598	−462	−619	−635	244		5,531	Very little increase when deepened 100 meters
44	1/42	679	−434	−600	−611	268		1,270	
45	12/41	641	−427	−585	−597	242	423	113,516	Increased from 8 to 423 M³ by deepening 100 meters
47	9/41	681	−473	−598	−610	156	190	49,395	
48	7/42	727	−378	−508	−533	813°	5	1,091	Produces from Gray Victor, top −886, TD, 2,563 meters
49	1/42	749	−393	−516	−531	256	15	3,635	
50	12/42	639	−428	−574	−583	1,124°	10	312	G. Vic. −886, Cach. −1,359, Potr. −1,689, TD, 2,921 meters
51	Drill.	635	−433	−593	−611				
58	Drill.	694	−406	−553	−570				G. Vic. −877
68	11/42	612	−523	−684	−708	272	10	115	

No. Well number
Comp. Month and year of completion
TLGT Top of Lower Gray tuffs
BVC Base of Violet conglomerate
BRC Base of Red conglomerate
TDV Top of Dark Victor
Pen. Penetration below top of Dark Victor
IP Initial production in cubic meters (1 M³ = 6.3 barrels)
Recov. Recovery in cubic meters to January 1, 1943
° Includes formations below Dark Victor

whose principal source is the poor quality of the samples from some wells caused by drilling difficulties and the nature of the section. The elevations of the principal markers and other well data are given in Table I. An attempt was made to obtain further information on the subsurface structure by means of seismograph

profiles, but failed on account of the poor quality of the few reflections obtained.

The top of the Lower Gray tuffs is the only recognizable horizon within the Tertiary section, and is considered a fairly reliable marker. It has been determined in all wells, giving the data shown in Figure 4. It may be readily seen

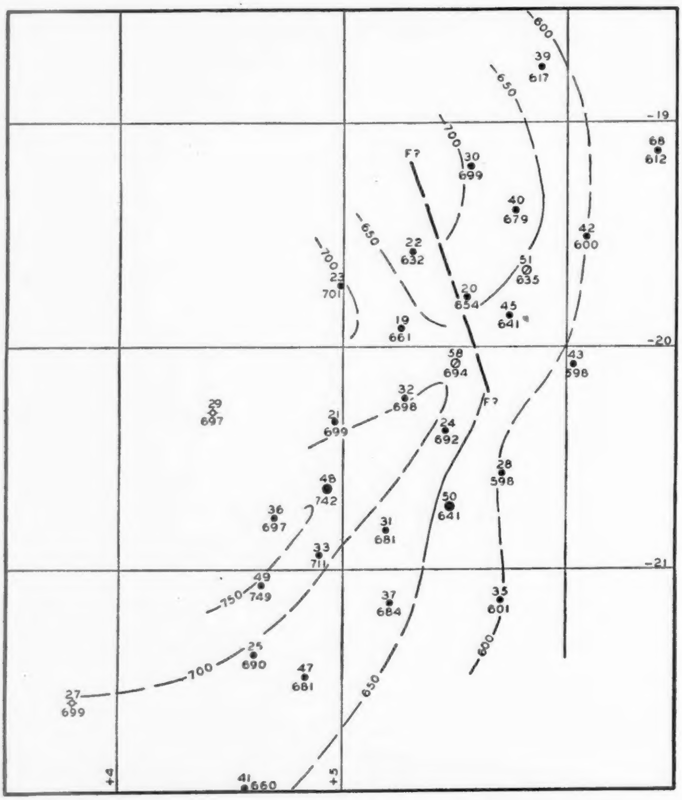

FIG. 4.—Generalized structure of Lower Gray tuffs, contour interval 50 meters. No attempt to show numerous faults believed to cut this formation.

that it is impossible definitely to interpret its structure with the limited data available, but that in any case it will be necessary to assume the presence of faults or sharp folds which can not be correlated with anything in either the surface beds or deeper formations. Since it is not believed that the large differences shown between some adjacent wells can be explained by errors in depth or sample determinations, an attempt has been made to explain them by a system of

low-angle thrust faults, as presented later under the description of the cross section of Figure 8.

The base of the Violet conglomerate is the next definite marker found in all wells, and its structure is shown in Figure 5. It is quite different from that of

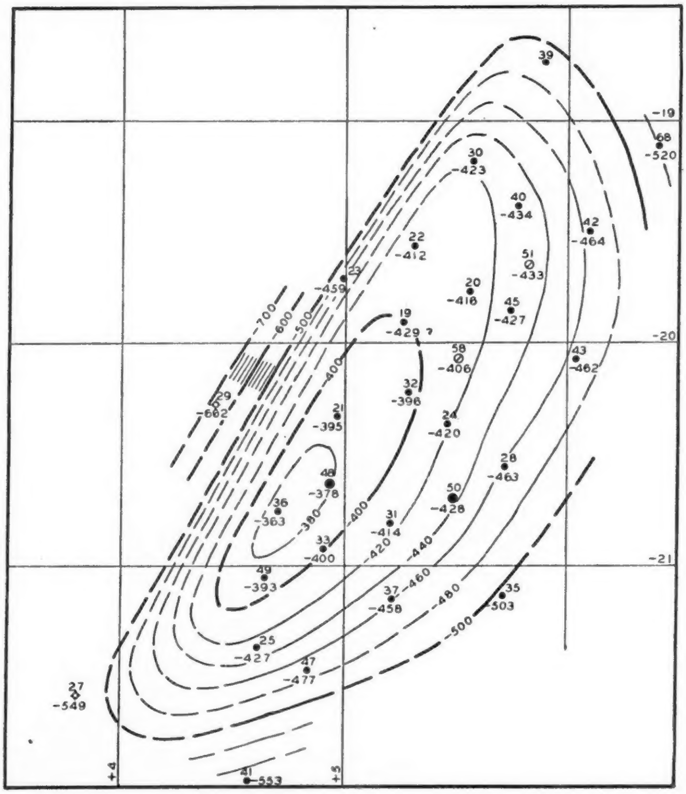

FIG. 5.—Structure of base of Violet conglomerate, contour interval 20 meters.

the surface or Lower Gray tuffs, but similar to that of the lower horizons. No faulting is shown on the west flank, as the dips shown by cores are high enough to account for the structural differences without the presence of faulting. It should be noted that considerable latitude is possible in the drawing of the axis and the form of the crest and west flank of the fold in this and all other subsurface maps.

Figure 7 shows the structure of the top of the Dark Victor. This is the best horizon for showing the deep structure, as it is readily distinguishable in the samples, is probably not affected by an unconformity, and the first showings of oil are generally obtained at an average of 10 meters below its top. Although

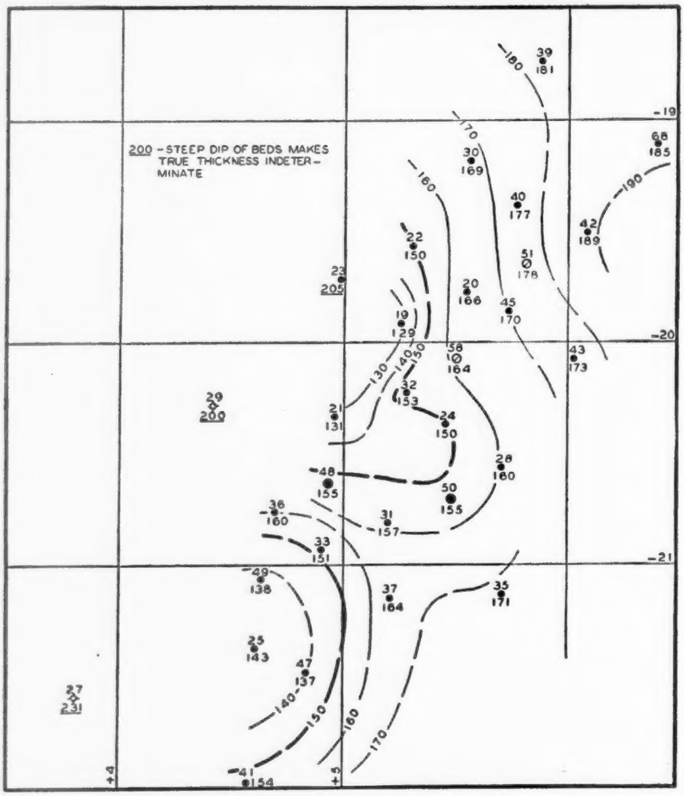

FIG. 6.—Interval between base of Violet conglomerate and top of Dark Victor. Isopach interval 10 meters.

its structure is similar to that of the Violet conglomerate, there are important differences between them. The interval between these two formations increases from a minimum of 131 meters in T 21 near the crest of the subsurface high to 181 meters in T 39 on the north end, 143 meters in T 25 on the south end, and 171 meters in T 35 on the east flank. Although thicknesses of 206, 231, and 200 meters, respectively, were found in wells T 23, T 27, and T 29 on the west flank, the un-

certainty about how much correction should be applied for the inclination of the beds makes it impossible to state definitely whether there is a similar increase in thickness toward the west. There are a number of irregularities in this general increase in thickness away from the crest, as shown in Figure 6, and these may be

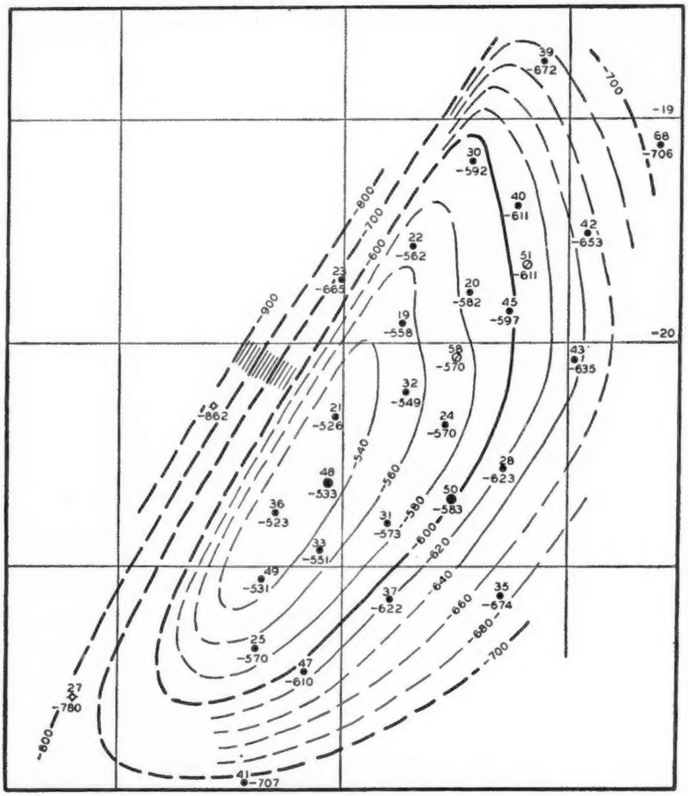

FIG. 7.—Structure of top of Dark Victor, contour interval 20 meters.

in part due to errors in the tops and in part due to irregularities in the erosional surface on which the Violet conglomerate rests. However, the general increase suggests that there was gentle folding at some time during the interval between the deposition of the Dark Victor and that of the Violet conglomerate, and that the later and more intense folding took place along the same general structural lines.

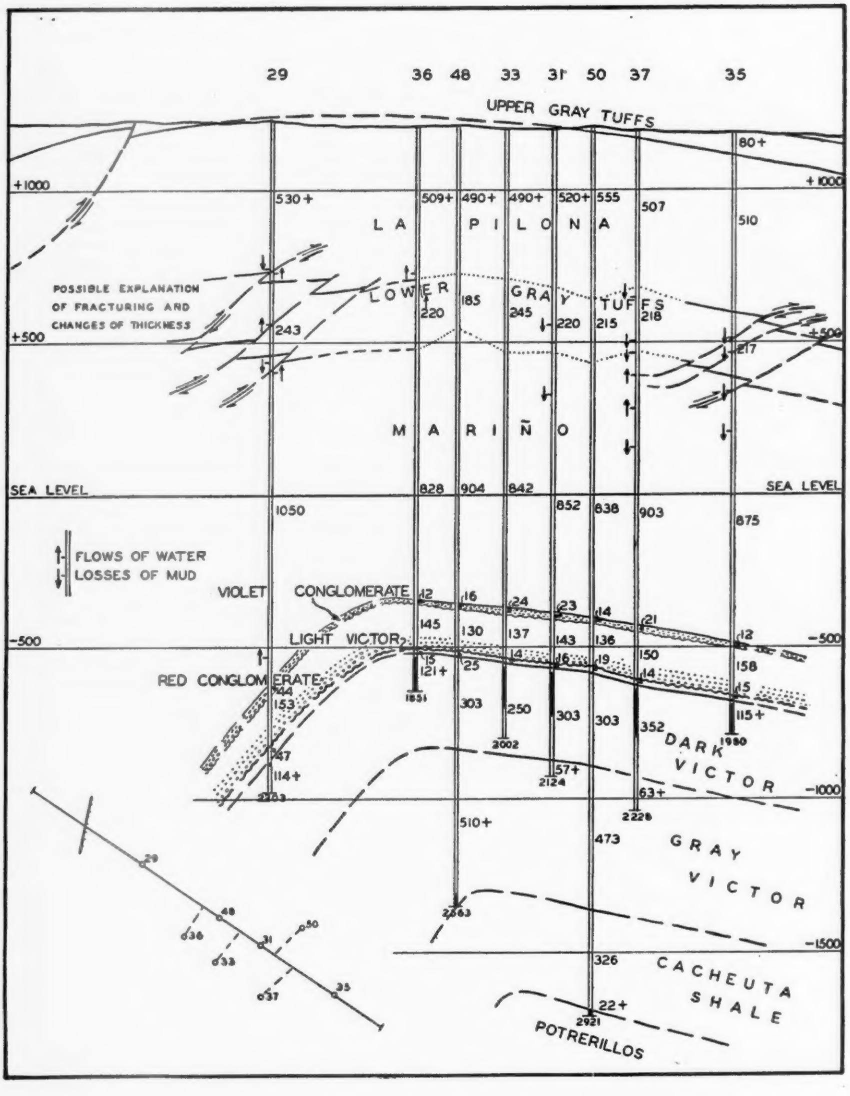

FIG. 8.—Transverse cross section of Tupungato field, showing relation between surface and subsurface structure, and possible explanation of variations in thickness of Lower Gray tuffs.

RELATION BETWEEN SURFACE AND SUBSURFACE STRUCTURE

The relation between the structure of the surface beds and that of the various lower beds is shown in Figure 8 by means of a transverse cross section through wells T 29, T 48, T 31, and T 35, which lie in a line passing through the crest of the fold and approximately at right angles with its axis, to which have been projected wells T 36 and T 50, which lie south and north, respectively, of that line. It is evident that the greatest structural change occurs between the Lower Gray tuffs and the Violet conglomerate, or within the Mariño. Since there is some evidence in outcrops of the presence of an unconformity at the contact of the tuffs on the Mariño, it would naturally be expected that these structural differences could best be explained by post-Mariño folding and erosion, and deposition of the tuffs on an irregular surface. However, this would imply the occurrence of folding during the late Miocene or early Pliocene, which although possible, remains to be proved, but would fail to explain the irregularities in the top of the Lower Gray tuffs. It is therefore necessary to consider other factors which may have a bearing on this problem.

During the drilling of the first deep wells, strong flows of salt water at abnormally high pressures were encountered at depths between 550 and 950 meters, or just above, within, and below the Lower Gray tuffs. Flows as high as 1,000 cubic meters (6,300 barrels) per hour were recorded, with shut-in surface pressures up to 40 atmospheres. Subsequent wells had either flows of water or losses of drilling mud from approximately the same part of the section, but found lower pressures. The high rates of flow, the variation in the stratigraphic level from which they came, and the failure of fibrous material to stop the losses of mud indicate the presence of fissures. This is confirmed by the fractured condition of cores of this part of the section in well T 10. The decline in the hydrostatic head throughout the entire area, which is attributed to the production of large volumes of water during the drilling of the early wells, indicates that there is communication between these fractures.

The presence of open fissures, the observed irregularities in the structure of the top of the Lower Gray tuffs, and the variations in thickness of the latter are possibly best explained by the presence of thrust faults which cut the tuffs at low angles with their bedding. The lack of any surface evidence of such faulting may be explained by its absorption by deformation and differential movements within the poorly consolidated sediments of the La Pilona. Such faults might be caused by compressive stresses with a component normal to the stratification of the tuffs, as their composition of fine angular grains with some degree of cementation would make them resistant to deformation, but susceptible to fracture. That such stresses may have been present may be readily imagined in view of the large number of thrust faults which are found throughout the area. Any purely lateral stresses might have been given a vertical component by the effect of the gentle arch in the underlying more competent formations which is indicated by the previously mentioned increase in interval between the Dark Victor

and the Violet conglomerate. This arch may have been accentuated to some extent before the initial occurrence of the faulting, after which, further folding of the lower beds and fracturing of the upper may have been contemporaneous.

If the foregoing hypothesis can explain the structure and the thickness changes of the Lower Gray tuffs, it would only be a step further in the same direction to apply it also as an explanation of the increase in thickness of the Mariño toward the west flank. In this case, wedges of the lower part of the Mariño, formed by thrust faults which cut the beds at low angles in front of the steep lower fold and pass into slippage along the bedding planes over the top and toward the east, may have caused a duplication of parts of the section which would give the observed increased thickness. If this were true, the necessity of placing an angular unconformity at the top of the Mariño, with its accompanying folding and erosion, would be obviated.

It is realized that there is little chance of either proving or disproving this interpretation at Tupungato, as this could not be done without the drilling of wells farther west, for which there is no justification, since the proof of its correctness is of no practical value in the further development of the field. However, if it should be accepted as a possibility, it would form a basis quite different from any heretofore used in this area for the prediction of the subsurface structure from that of the surface.

The general form of the lower structure suggests that the most important fault of the Tupungato field may be an underthrust which cuts the west flank at an unknown depth, and whose plane is inclined toward the east at a low angle, below which there might be no anticlinal structure.

GEOLOGIC HISTORY

The geologic history of this region prior to the Triassic is not believed to be of importance in connection with the Tupungato field, and it should suffice to mention that the Paleozoic sediments which are found in the foothills on the northwest and west and also in the Sierra Pintada, 160 kilometers south, have been intensely folded, faulted and metamorphosed, probably by the diastrophism of Hercynian (late Pennsylvanian) age as reported by Stappenbeck[18] and Kiedel[19] in the Sierra de Uspallata, 80 kilometers north. The Tupungato area was probably also involved in these movements.

During the early Triassic there was widespread igneous activity in Mendoza. The rhyolite flows and associated tuffs found at Cerro Cacheuta and in the wells of the Barrancas field are believed to be contemporaneous with those of the Sierra de Villavicencio which have a thickness which may reach 1,000 meters, and which are assigned by Harrington[20] to the Middle Triassic, and those of the Sierra

[18] R. Stappenbeck, "La Precordillera de San Juan y Mendoza," *Anales del Ministerio de Agricultura*, Tomo IV, No. 3 (Buenos Aires, 1910).

[19] J. Keidel, "Las Estructuras de Corrimientos Paleozoicos de la Sierra de Uspallata," *Physis*, Tomo XIV, No. 3 (Buenos Aires, 1939), pp. 3–96.

[20] H. J. Harrington, *op. cit.*, pp. 18–20.

Pintada and southwestern Mendoza, which are assigned by Groeber[21] to the Permo-Triassic. They may therefore have a wide distribution, and may be expected to underlie the Tupungato field.

After a period of erosion, during which the preceding lavas were greatly weathered and altered, the succeeding sediments were deposited under continental conditions in a basin which covered parts of the provinces of Mendoza and San Juan in Argentina, and possibly extended into Chile.[22] Harrington[23] reports the presence of unconformities and lava flows within this section in the Villavicencio area, and the lithologic character of the Upper Triassic sediments of the Tupungato area confirms the presence of volcanic activity in adjacent areas. It is probable that there were a number of interruptions in the sedimentation and some gentle folding during this period, as shown by the variations in the thickness of the various stratigraphic divisions within each of the oil fields of northern Mendoza.

Although several stages of the Jurassic, separated by unconformities, are represented by thick series of both continental and marine sediments in Neuquen and southern Mendoza, and remnants of them have been found in the Andean Cordillera 90 kilometers southwest of the Tupungato field,[24] and at Paso de Espinacito, 140 kilometers northwest,[25] no deposition is known to have taken place within the area in which the Upper Triassic sediments of Mendoza are found.

The Lower Cretaceous is represented in Neuquen and southern Mendoza by a thick section of marine sediments, and is probably also present in the aforementioned localities in the Cordillera, but it is not known to occur within the limits of the Upper Triassic basin.

The Upper Cretaceous, which is represented by thick continental deposits in Neuquen and southern Mendoza, is not definitely known to be present in this area, although a part of the section now included in the Upper Triassic was formerly assigned to the Cretaceous, probably because of its lithologic similarity to that of the area on the south.

During the Jurassic and Cretaceous there were at least two periods of diastrophism in southern Neuquen, but there is no record of their having affected this area to any extent.

Groeber[26] has classified the various diastrophic movements of the Tertiary into three groups. The first, of Eocene age, resulted in the intense folding of the Cretaceous beds of Neuquen and southern Mendoza and probably also the extreme western part of northern Mendoza, into parallel anticlines and synclines

[21] P. Groeber, *op. cit.*, pp. 174–75.

[22] E. Trumpy, unpublished report of the YPF.

[23] H. J. Harrington, *op. cit.*, pp. 20–27.

[24] E. Trumpy, unpublished report of the YPF.

[25] P. Groeber, "Estratigrafía del Dogger en la República Argentina," *Ministerio de Agricultura, Dirección de Minas, Boletín 18*, Serie B (Buenos Aires, 1918).

[26] P. Groeber, "Mapa Geológico de Mendoza," *op. cit.*, pp. 210–11.

with associated thrust faults, and was followed by volcanic activity. The second, in the early Miocene, resulted in the uplift and faulting of a large area, whose erosion furnished the material for the lower part of the thick Tertiary section of Mendoza. The only evidence of the presence of either of these two movements in the Tupungato area is the variation in the thickness of the beds between the bases of the Red and Violet conglomerates.

The first phase of the third movement is placed in the basal Pliocene, during which there were further vertical movements. This may be responsible for the unconformity noted at the top of the Mariño, and for the renewed erosion which resulted in the deposition of the sediments above that formation. The principal phase of the third movement, at the end of the Pliocene, resulted in the formation of the present Cordillera of the Andes. Although the most prominent effect was the uplifting of large blocks within the Cordillera, it is the writer's belief, based on the character of the faulting in the vicinity of the Tupungato field, that it was accompanied by strong lateral compression toward the east, which caused extensive thrust faulting in the foothills area. It is possible that these movements continued into the Quaternary, after which the present topography was formed by extensive erosion by water, ice, and wind.

OCCURRENCE AND CHARACTER OF OIL

SHALLOW ZONE

The oil found in the shallow wells is evidently associated with faults and fractures, as shown by the production of large volumes of salt water and the variation in the stratigraphic levels at which it was found in the different wells. The oil which has saturated some of the sandstone outcrops in the center of the structure probably reached them by farther ascent along the same fractures. It was at first supposed that the low structural position of wells T 26 and T 29 on the west flank could be best explained by the presence of a normal fault with a downthrow on the west, whose plane of fracture provided a path for the ascent of the oil from some lower formation to the shallow zone. However, the presence of a normal or tension fault seems improbable in an area where the major movements are due to compressive stresses, so that it is very questionable whether the upper oil has such a simple relation to the lower. The close association of large volumes of water with the shallow oil, and the lack of any appreciable quantity of water in the Victor zone, make it appear that although both accumulations may have been derived from the same common source, the upper was not directly derived from the lower.

VICTOR ZONE

As described under the stratigraphy, the "sandstones" of the Dark Victor are in reality the result of alteration of the tuffs, and their presence should therefore be more closely related to the fracturing than to the stratigraphic position and their distribution should be very erratic, as has been mentioned. No relation

has been observed between the relative amounts of "sandstones" present in a well and its productivity. Although oil saturation has been noted in them, their extremely low permeability makes it improbable that they directly contribute any appreciable amount of oil to the wells. The irregular pores in the tuffs are also doubtful sources of more than a small part of the oil to the wells, and it must therefore be assumed that the openings associated with the fractures are the principal means by which the oil enters the wells, although the "sandstones" and porous tuffs may contribute to the total recovery by furnishing some oil to these fractures, with the large surface cut by them compensating for the low permeability. This hypothesis is supported by the fact that wells with the highest productivity are located near the axis or on the north or south flanks where the beds have suffered the maximum deformation and the maximum fracturing is to be expected, while the poor wells are on the east flank where the dip is nearly uniform and there has been little disturbance other than tilting. Further evidence of the presence and importance of the fractures is given by the effect of some wells on the production of others, and the decline of pressure in certain areas prior to the production of oil from them, both of which show a degree of communication which could not be expected without their presence.

Although the percentage volume of the openings must be small, the great thickness of the Dark Victor and the probability that the porosity feeds oil to the fractures, make possible a large total oil content.

The first showings of oil are generally noted after drilling approximately 10 meters into the Dark Victor, but there is no relation between penetration and initial production between different wells, and no direct relation in any one well, nor can it be predicted where the best production will be obtained. Since only relatively small quantities of water have been found, and these do not appear to be related to either the structural position of the well or the amount of penetration of the Dark Victor, there is no uniformity in the total depths to which the wells have been drilled, as may be seen from Table I. It has been generally observed that the upper third of the Dark Victor furnishes the greater part of the oil, the middle third much less, and the lower third very little, although there are some exceptions, particularly T 45, where practically all of the initial production of 423 cubic meters came from the lower half.

Although the overlying Light Victor is also fractured and has given showings of oil in some wells, it is cemented to a greater degree than the Dark Victor, and either it or the overlying Red conglomerate must form the impermeable cover for the oil accumulation.

DEEPER ZONES

Little can be said about the occurrence of oil in the deeper zones of wells T 48 and T 50. Although some sandstones and conglomerates are present in the sections from which the oil is produced in both wells, it is quite possible that they are of very low permeability and that the oil is derived directly from the fractures.

CHARACTER OF OIL

The oil of both the shallow zone and the Dark Victor is similar to that found in all of the other oil fields of northern Mendoza, and its most notable characteristic is its high viscosity at ordinary atmospheric temperatures due to its high content of paraffine. The oil from the Gray Victor of well T 48 is of slightly higher gravity than that of the Dark Victor, but of similar characteristics and the same black color. However, the oil of the Potrerillos from T 50 is light green in color and not as viscous. The following data give a comparison between these two crudes.

	Dark Victor	*Potrerillos*
	T 19	T 50
Specific gravity at 15°C.	0.8595 (33.1° API)	0.839 (37.7° API)
Color	Black	Light green
Viscosity, Saybolt Universal	254 sec. at 38°C.	49 sec. at 50°C.
	Percentage	*Percentage*
Carbon, Conradson	4.83	
Ash	0.01	
Sulphur	0.18	
Paraffine	12.21	7.8
Distillation test		
Gasoline	11.5	22.2
Kerosene	9.7	14.8
Gas oil	6.7	9.3
Residue	71.6	53.2
Losses	0.5	0.5

The following data give the temperature-viscosity relations for a sample of oil from well T 20 (Dark Victor).

55°C.	76 sec. Saybolt Universal
50	90
45	102
40	124
35	186
29	Inf.

A number of measurements show that the temperature within the Dark Victor reservoir is approximately 85°C. (185°F.). At this temperature, and with the further decrease that would be caused by the solution of 50 cubic meters of gas per cubic meter of oil (280 cubic feet per barrel), the viscosity of the oil under reservoir conditions may not be excessively high, although no data are available to give it a definite value.

No data are available on the temperature or the amount of gas in solution within the Potrerillos reservoir.

DRILLING AND PRODUCTION

Drilling has been done by Diesel-powered rotaries. The general program for the Dark Victor wells has been to cement 13⅜-inch surface pipe at approximately 100 meters, below which a 12¼-inch hole is drilled until the fractured zones are passed. This is the most difficult part of the drilling, as if the mud is too heavy, it will be lost, and if it is too light, the water may wash it out of the hole. In many of the early wells it was found impossible to prevent the flow of the water, and drilling was continued with the wells flowing large volumes of water. As the pressure of the water decreased and improvements were made in the quality of the mud, it became possible to control the flow of the water, but the possible loss of mud always presents a threat, and it is impossible to predict the depths at which it may occur. When the fractured zone is believed to have been penetrated, at depths which vary from 800 to 1,200 meters, an intermediate string of 9⅝-inch casing has been cemented and drilling continued with 8½-inch bit to the top of the Victor, where 7-inch casing is cemented. After drilling to approximately 150 meters below the top of the Dark Victor, liner is run, and the well tubed, washed, and swabbed to start natural flow. If a satisfactory production is not obtained, further deepening is considered.

Some cores were taken in a few of the earlier wells, but the majority have been completed without any coring. No complete electric log has been made of any well, but it is questionable whether this method would be of value to indicate the depths at which oil would enter a well.

Development was first planned on an equilateral triangle pattern with sides of 300 meters, giving an area of 7.8 hectares (19 acres) per well. It was later decided to omit alternate rows of wells in a direction transverse to the axis, giving a rectangular pattern, 300 meters by 520 meters, with the long direction parallel to the axis. However, since the intercommunication between all parts of the reservoir has been shown to be present by pressure data, and since some wells have been found to be affected by the production of adjacent ones, no additional development of the Dark Victor is planned at present within the proved area, with the possible exception of the location T 40 on the south plunge of the axis.

If the lower horizons prove to be productive, the 9⅝-inch casing will be carried to the top of the Victor, and the 7-inch casing cemented as nearly as possible to the top of the lower "pay."

PRODUCTION

Table II gives the daily average oil production and number of producing wells by months since the discovery of the Dark Victor zone to January 1, 1943. The total recovery to that date of 1,381,020 cubic meters (8,700,000 barrels) has been produced from an area of approximately 235 hectares (580 acres), although there has undoubtedly been some drainage from surrounding areas. This gives a unit recovery of 5,880 cubic meters per hectare (nearly 15,000 barrels per acre) to that date. It is probable that the productive area might be extended somewhat farther

TABLE II

PRODUCTION DATA
(Cubic meters)

	Month	*Monthly Total*	*Daily Average*	*Number Wells*
1938	July	1,458	47	1
	Aug.	8		1
	Sept.	56	2	1
	Oct.	61	2	1
	Nov.	4,510	153	1
	Dec.	5,149	166	1
		11,242		
1939	Jan.	4,596	148	1
	Feb.	4,319	154	1
	Mar.	4,402	142	1
	Apr.	4,487	150	2
	May	5,892	190	2
	June	5,758	192	2
	July	7,152	231	2
	Aug.	11,676	376	3
	Sept.	11,481	383	3
	Oct.	13,158	423	4
	Nov.	19,243	641	4
	Dec.	21,085	678	4
		113,249		
1940	Jan.	19,014	612	5
	Feb.	15,449	533	6
	Mar.	23,966	772	6
	Apr.	25,350	845	7
	May	25,508	821	7
	June	30,962	1,032	7
	July	35,685	1,151	7
	Aug.	34,875	1,125	7
	Sept.	36,756	1,225	7
	Oct.	41,116	1,324	8
	Nov.	39,052	1,302	9
	Dec.	40,057	1,292	9
		367,790		
1941	Jan.	39,856	1,285	10
	Feb.	36,263	1,290	11
	Mar.	35,285	1,138	12
	Apr.	33,836	1,128	12
	May	38,169	1,231	14
	June	38,657	1,288	15
	July	39,186	1,260	15
	Aug.	36,114	1,161	16
	Sept.	34,911	1,164	17
	Oct.	46,392	1,490	17
	Nov.	43,077	1,436	17
	Dec.	43,009	1,387	19
		464,755		
1942	Jan.	42,840	1,382	22
	Feb.	37,436	1,337	22
	Mar.	41,139	1,327	22
	Apr.	36,047	1,202	22
	May	33,683	1,086	23
	June	28,841	962	23
	July	35,915	1,159	24
	Aug.	36,290	1,171	24
	Sept.	33,677	1,123	24
	Oct.	34,236	1,104	24
	Nov.	31,313	1,044	25
	Dec.	32,567	1,051	26
		423,984		

north and south, but the low initial productions of the latest completions do not encourage further drilling. The areal distribution of the recovered oil may be seen by reference to the individual well data of Table I.

On January 1, 1943, one well was shut down, five wells were pumping, and the remainder were producing by natural flow. Well T 22, which had produced a total to that date of 331,068 cubic meters (2,080,000 barrels), was still flowing at the rate of 229 cubic meters (1,440 barrels) per day.

WATER PRODUCTION

The production data of individual wells show that although some water is present within the reservoir, it is distributed without regard to either structural position or stratigraphic level. Well T 23, on the west flank, with a total depth of −939 meters, showed 3 per cent water when completed, which later increased to 40 per cent. However, at the present low rate of production of this well, this amounts to less than 3 cubic meters per day. Wells T 27 and T 29, both of which are low on the west flank with total depths of −926 and −976 meters, respectively, and are not commercially productive, also showed water with the oil on their first tests. Well T 35, the farthest advance on the southeast flank, with total depth of −789 meters, also showed a small amount of water on completion, although exceeded in both depth and penetration by many other wells which have shown no water after long production. Well T 22, which has had the highest recovery, now shows variable amounts up to 13 per cent, which appeared after the production of a large quantity of oil. Three other wells produce amounts up to 5 per cent, while the remainder have no water or only a trace.

These data show that some water was originally present within the developed limits of the Dark Victor, but irregularly distributed without any apparent relation to the structure or stratigraphy. However, they do not show definitely whether additional water is entering the reservoir. Even small quantities of water are undesirable, as they emulsify readily with the oil, necessitating the use of heat and chemicals for its removal as well as giving a high salt content to the oil.

There is a radical change in the concentration and composition of the various waters from the surface downward. The salinity increases with depth, being approximately 40 grams per liter in the water of the Mariño, and 60 grams per liter in that of the Dark Victor (T 23). The Tertiary waters contain calcium and sodium chlorides in the proportion of 2 to 1, with little or no sulphates, while the lower waters are approximately the reverse in the calcium-sodium ratio, and contain sulphates.

ULTIMATE RECOVERY FROM DARK VICTOR

It is difficult to estimate the ultimate recovery which may be expected from the Victor zone, as the peculiar characteristics of both the reservoir and the oil make it dangerous to apply the method which is based on the relation of the pressure decline to the withdrawals of oil and gas. A cubic meter of the oil contains approximately 50 cubic meters of gas (280 cubic feet per barrel) in solution under the original conditions of 232 atmospheres pressure and 85°C. temperature, but

this volume is only sufficient to saturate it at a pressure of between 90 and 100 atmospheres. Since no pressure as low as the latter has been measured in a producing well, no gas has yet been released from solution within the reservoir, and all of the oil that has been produced must have been brought to the wells by the expansion of the oil itself and any water that may be in contact with it.

If the oil is in contact or is connected by fractures or permeable zones with a relatively large volume of water, the pressure decline may have been lessened by the movement of water into space formerly occupied by oil. Since the rate of entrance of the water should increase as the average pressure of the reservoir declines, the net effect of such an encroachment would be an increase in the volume of oil produced for each unit of pressure decline. To determine whether such a condition exists, it would be necessary to have accurate values of the average reservoir pressure at various stages in its producing history. However, these are difficult to determine, because of the probable large variation in the volume of oil under each unit of area in the different parts of the field. An areally weighted average would probably be too high, as the higher pressures which now exist in the areas of low productivity may affect only a relatively small part of the total oil content. A satisfactory method of weighting has not yet been devised.

If no water is entering the oil reservoir, an estimate of the original oil content might be made from a comparison of the volume of oil produced per unit of pressure decline with the expansibility of the oil under reservoir conditions for the same unit of pressure decline. Since this method gives an absurdly large volume of oil when areally weighted pressures are used, it is evident that either the pressures are greatly in error, or that they are being partially maintained by the entrance of water.

Another factor which may be of importance with respect to the ultimate recovery and which is difficult to predict is the effect on the production of the release of dissolved gas within the reservoir.

When all of the conflicting evidence is considered, the only definite statement that can be made at this time is that there is no effective water drive in the Dark Victor reservoir under the present conditions of pressure and rate of withdrawal, and that sufficient facts are not available to make an accurate estimate of either the original oil content or the ultimate recovery.

DEEPER POSSIBILITIES

The existence of other oil-bearing formations at greater depths is considered possible in view of the fact that the Potrerillos formation, which produces oil in Cacheuta and Lunlunta, has been penetrated only 18 meters, and that the Green conglomerate and Volcanic series, which are productive in the Barrancas field, have not been reached. Two wells, T 51 and T 58, are now drilling to test the possibilities of deeper zones of the Potrerillos.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 10 (OCTOBER, 1944), PP. 1485-1505, 1 FIG., 4 CHARTS

WORLD PETROLEUM RESERVES AND PETROLEUM STATISTICS[1]

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ABSTRACT

Unquestionably, the Age of Oil is with us now and it probably has not as yet reached its majority. Petroleum in its common forms has become a part of our daily life. The United States has not only been the greatest oil-producing nation in the world; it has also been the greatest consumer. After the war we shall unquestionably continue to be one of the greatest users of petroleum, but the world-wide demands also will be greater.

Wallace E. Pratt is quoted as saying that oil in the earth is abundant. We shall not try to refute that general statement. Rather, let us see how much oil the Good Earth has produced in the past; what it is now producing; and where the presently known areas of petroleum abundance are located. Furthermore, and this should concern us most, what does the future hold for the United States? We have to the best of our knowledge less than half of the known petroleum reserves of the world, but we are producing yearly approximately 65 per cent. This ratio of known production to reserves is not just a wartime development—it has been going on for years. We have been prodigal with our oil supplies and we must now recognize the world-wide importance of petroleum and the desirability of having a definite governmental policy for maintaining a strong industry with adequate reserves, both domestic and foreign. The record of accomplishment of the petroleum industry in the United States is of the highest order and if free and independent industry is permitted the right of way, unhampered by Government control, but, in lieu thereof, aided by a sympathetic understanding of the industry's problems, the petroleum independence of the United States will be preserved.

Statistics show that the United States has had a cumulative production amounting to 28 billion barrels of oil compared with 15½ billion barrels for the rest of the world. Our proved reserves, according to the estimates of the American Petroleum Institute, total 20 billion barrels compared with an indicated oil reserve of 31-41 billion barrels for all other producing countries. During 1941, the last year for which accurate world production figures are available we produced more than 63 per cent of the total world's production. Furthermore, our areas favorable to oil accumulation have been and are being exploited to a far greater extent than those in many other parts of the world.

Estimates of the indicated crude-oil reserves of the world range from approximately 51 to 61 billion barrels. They are unevenly distributed over the face of the globe. Two areas of similar size on the opposite sides of the world, the Persian Gulf and Caspian Basin in the Old World and the countries of Venezuela, Colombia, Mexico, and the United States in the New World, have more than 95 per cent of the indicated reserves of the world.

Oil has often been called Black Gold. You might carry the analogy further and say that what gold was to mankind during the Middle Ages, oil is to-day. The alchemist of old sought to add to mankind's riches by transmuting abundant baser substances into gold—so the chemist of to-day has made life richer by giving us a vast array of useful products derived from crude oil, and may in the future be called upon to transmute the vast deposits of oil shales and coal into petroleum and its derivative products.

Unquestionably, the Age of Oil is with us now and it probably has not as yet reached its majority. Petroleum in its now commoner forms has become a part of our daily life. Hundreds of new uses are being found for oil and a products list is like a Who's Who directory. Synthetic rubber is only one of more than 300 by-products of modern oil-refining processes, and it only remains for peace-time industry to develop these uses and products which will contribute to man's comfort and well-being on a scale heretofore unknown.

[1] Read before the Association at Dallas, March 23, 1944. Manuscript received, August 7, 1944.

[2] Standard Oil Company of California.

The United States has not only been the greatest oil-producing nation in the world; it has also been the greatest consumer. After the war we shall unquestionably continue to be one of the greatest users of petroleum, but the world-wide demands also will be greater. The present war is far more global than any in the past. It is a war of wheels and wings. The uses and appliances of petroleum and its products are so vast and important that their influence is becoming universal. The Arab is no longer content with his camel to plod over the sands at 2–3 miles per hour. He wants a "jeep" that can navigate the worst sand dunes at 20–30 miles per hour.

The primitive farmer will wish to exchange his spade and wooden plow for a tractor. Aviation will bring all peoples of the world close together—far closer than ever before, and wings and wheels and mechanized equipment of all kinds from ice boxes to bug killers—all dependent on oil, will make presently inhospitable, unhealthful, remote places of the earth, from the frozen tundras of the north to the torrid zones of the tropics, more suitable places for mankind to develop.

So, for the world at large, the Age of Oil is upon us. The question is, where is all this oil to be found and how long will it last? Wallace Pratt[3] has said that oil in the earth is abundant. We shall not try to refute that general statement. Rather let us see how much oil the Good Earth has produced in the past, what it is now producing and where the presently known areas of petroleum abundance are located. Furthermore, and what should concern us most, is what the future holds for the United States. We have, to the best of our knowledge, less than half of the known petroleum reserves of the world, but we are producing yearly something more than 65 per cent. This ratio of production to known reserves is not just a wartime development—it has been going on for years. We have had a long cycle of years during which our productive capacity has exceeded demand. Possibly the United States has been like the covetous man of the old fable—who killed the goose that laid the golden egg. We have not quite killed the goose, but we have plucked out a lot of feathers.

It is now a well recognized fact, particularly within the Petroleum Industry, that we have been prodigal with our oil supplies in the United States. We may, if we do not wait too long, have some good cards up our sleeve that we can play when the going becomes really rough, that is, at a price we shall be able to maintain our petroleum independence of the rest of the world. This petroleum independence must be maintained at all cost. We must never permit ourselves to be caught short-handed in the event of other wars in which we may become involved.

Also, we must recognize the continually growing demands for petroleum for peace-time industrial and commercial needs.

We must recognize the world-wide importance of petroleum and the desirability of having a definite governmental policy for maintaining a strong industry with adequate reserves, both domestic and foreign. We can no longer afford to be provincial and should know as accurately as possible the size and availability

[3] Wallace E. Pratt, *Oil in the Earth*, University of Kansas Press (1942).

of our own oil and gas reserves, and, because of their world-wide importance, we should know more about the size and location of the reserves of foreign countries and how to correlate and use them judiciously with those within the United States.

Our present knowledge of the petroleum reserves of the world outside of the United States varies from good to bad. For a few countries we have data which permit the setting up of proved reserves with about the same degree of accuracy as that used here in the United States. In some countries, for example the U.S.S.R., the national policy governing petroleum has been one of secrecy and the data which have leaked out, both about production and more particularly about reserves, have been very limited. Russian engineers are reported to have made estimates of their reserves which run as high as 8,640,000,000 tons (more than 50 billion barrels). Professor I. Gubkin[4] in 1939 evaluated the explored and visible reserves of the U.S.S.R. at 2,420,000,000 tons, approximately $14\frac{1}{2}$ billion barrels. Presumably the latter figure is intended to convey the idea of proved reserves, but we have no knowledge of the methods Gubkin used or just what he meant by "explored and visible reserves." We also find that some British- and American-controlled companies have adopted policies of withholding essential data which might permit the making of satisfactory estimates of the reserves of foreign fields in which they hold interests. Therefore, it should be understood that the degree of accuracy of reserve figures used in the following tabulations is variable. As examples, reserve estimates for the United States are good compared with those for the Netherlands East Indies. Those for the Netherlands East Indies are good compared with those for the Persian Gulf, and those for the Persian Gulf, are, in turn, much better than those for the U.S.S.R.

On the other hand, the production and cumulative production figures used in the charts and curves that follow are reasonably good except for the fact that since the outbreak of the present war, we have no good gauge of how much oil the Axis nations have produced.

Statistics show that the United States has had a cumulative production amounting to 28 billion barrels of oil compared with $15\frac{1}{2}$ billion barrels for the rest of the world. Our proved reserves, according to the American Petroleum Institute estimates, total 20 billion barrels compared with an indicated oil reserve of 31–41 billion barrels for all other producing countries. During 1941. the last year for which we have accurate production figures of the world, we produced about 63 per cent of the total world production.

Some interesting comparisons and correlations may be drawn between the reserves and production histories of the United States and her major producing states on the one hand, and the world and its major producing countries on the other.

Chart No. 1 shows an inset panel, on which are plotted the percentage of proved reserves of the United States allocated to the principal producing states and the percentage of production of these states to the production of the United States for the year 1943. The column on the left, a heavy, dotted line, represents

[4] *World Petroleum* (April, 1939).

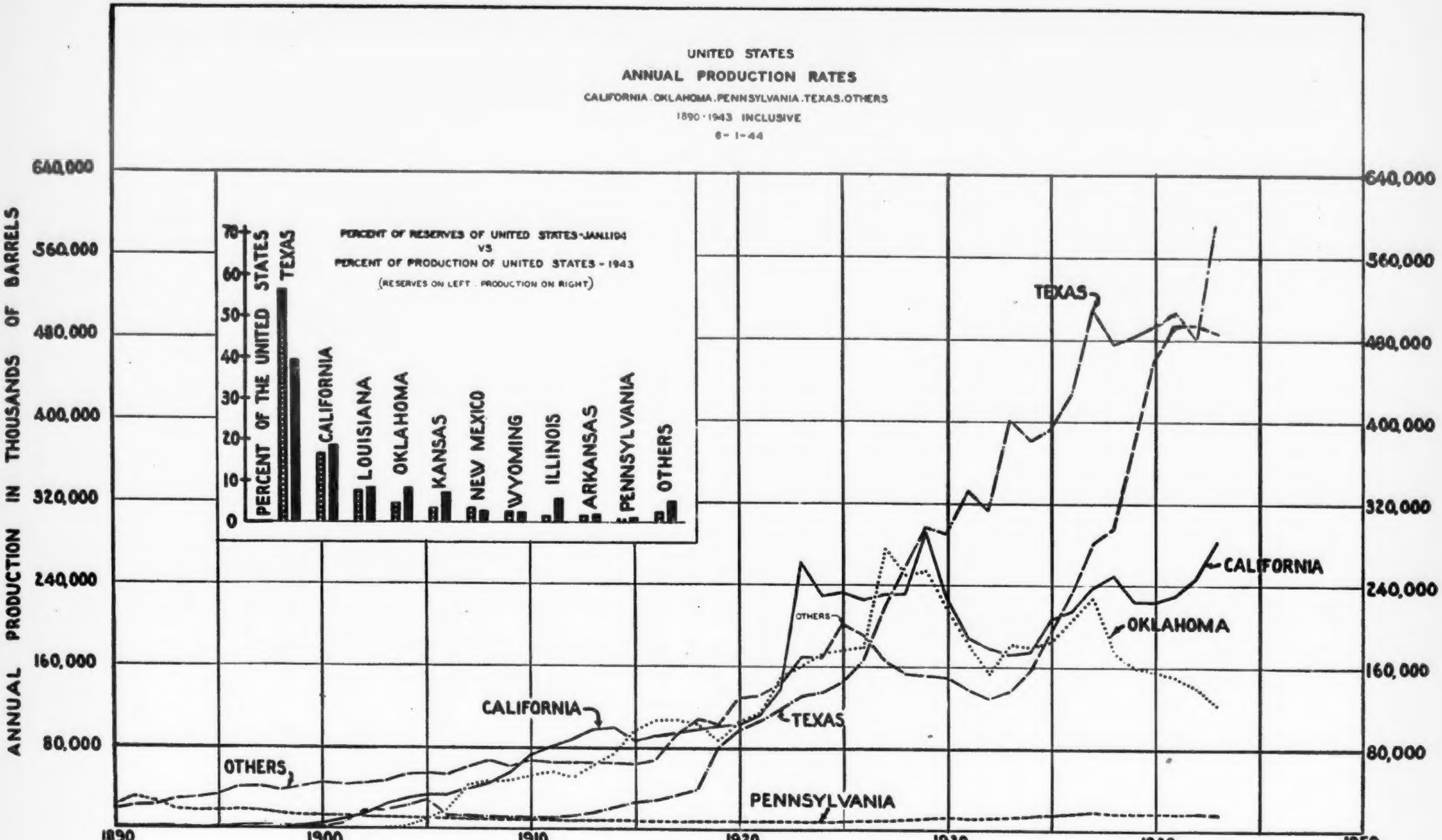
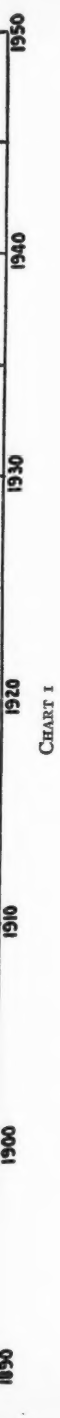

UNITED STATES
ANNUAL PRODUCTION RATES
CALIFORNIA . OKLAHOMA . PENNSYLVANIA . TEXAS . OTHERS
1890 - 1943 INCLUSIVE
6 - 1 - 44
ANNUAL PRODUCTION IN THOUSANDS OF BARRELS
640,000
560,000
480,000
400,000
320,000
240,000
160,000
80,000
1890
1900
1910
1920
1930
1940
1950
PERCENT OF RESERVES OF UNITED STATES - JAN.1.194
VS
PERCENT OF PRODUCTION OF UNITED STATES - 1943
(RESERVES ON LEFT . PRODUCTION ON RIGHT)
PERCENT OF THE UNITED STATES
70
60
50
40
30
20
10
0
TEXAS
CALIFORNIA
LOUISIANA
OKLAHOMA
KANSAS
NEW MEXICO
WYOMING
ILLINOIS
ARKANSAS
PENNSYLVANIA
OTHERS
TEXAS
CALIFORNIA
OKLAHOMA
OTHERS
CALIFORNIA
TEXAS
OTHERS
PENNSYLVANIA

CHART I



the reserves. The solid line on the right is plotted to depict the production for the year 1943. Texas has 56 per cent of the total United States reserves, but produced only 40 per cent of that year's production.

The state of California, second to Texas in both reserves and production had 17 per cent of the country's reserves and 19 per cent of the production. New Mexico follows Texas but in all the other states the percentage production exceeded the percentage of total reserves.

The graphs of Chart No. 1 show the annual production rates (1890–1943 inclusive) of Texas, California, Oklahoma, Pennsylvania, and all others combined (Pennsylvania is included as being representative of the production of the old Appalachian fields). California was the largest producer of any single state from 1903 to 1914. when Oklahoma caught up, and their production was about equal for the ensuing 14 years. Texas was relatively low at the start, but, from 1916 on, Texas' annual production mounted rapidly, overtaking both California and Oklahoma in 1928, when each of the three had a yearly production approximating 250 million barrels. Since then, Texas has forged rapidly ahead, both in yearly production and in proved reserves. At the present time, the reserves of Texas are 3.5 per cent times those of California, and more than half of the total of the United States.

The following table taken from the last annual report of the American Petroleum Institute records shows the proved petroleum reserves of the United States by states.

ESTIMATED PROVED PETROLEUM RESERVES IN UNITED STATES
(Barrels of 42 U. S. gallons)

	Proved Reserves as of December 31, 1943
Arkansas	296,929,000
California	3,336,823,000
Colorado	45,111,000
Illinois	294,622,000
Indiana	31,039,000
Kansas	645,852,000
Kentucky	35,190,000
Louisiana	1,483,826,000
Michigan	55,248,000
Mississippi	38,872,000
Montana	108,057,000
Nebraska	1,000,000
New Mexico	653,981,000
New York	90,525,000
Ohio	32,643,000
Oklahoma	908,618,000
Pennsylvania	137,323,000
Texas	11,324,954,000
West Virginia	43,839,000
Wyoming	499,394,000
Miscellaneous**	306,000
Total United States	20,064,152,000

** Includes Florida, Missouri, Tennessee, Utah and Virginia.

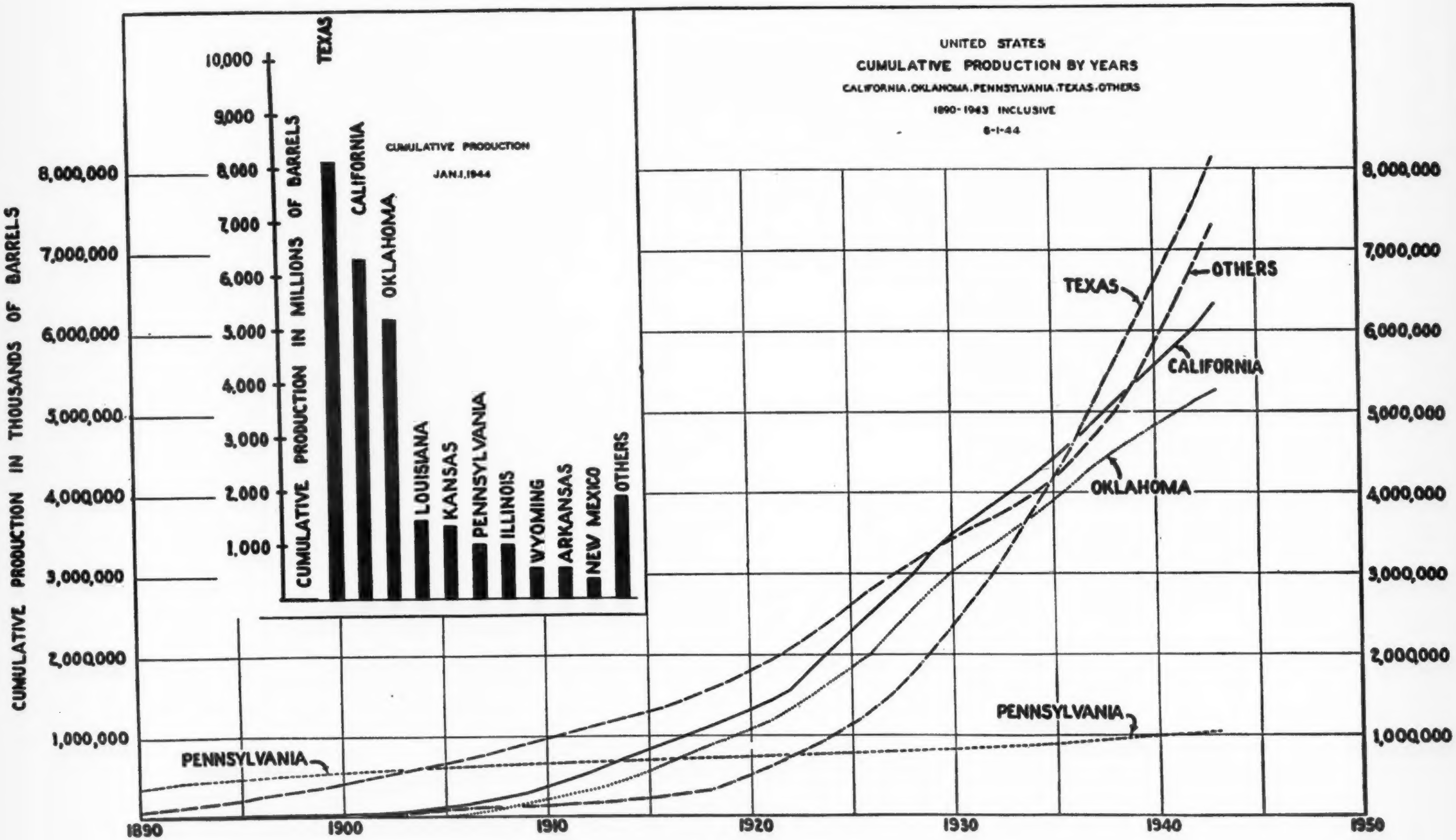
Chart No. 2 likewise includes a panel on the left, on which is plotted the cumulative production in millions of barrels for the larger oil-producing states. Texas again leads with a total of 8.2 billion barrels, California next with 6.3 billion, and Oklahoma with 5¼ billion barrels. The rest of the states are far behind. None of them has quite reached the 2-billion-barrel mark. In fact, the total cumulative of all states excepting Texas, California, and Oklahoma, is only a little more than that of Texas. These three great oil-producing states have produced 70 per cent of the total cumulative production of the United States. The cumulative production by years plotted on this chart shows that California cumulative production mounted rapidly from 1910 to the present time. The cumulative for Texas did not exceed that of California until 1936, but since then Texas has produced more than 2½ billion barrels in excess of California. The curve for Oklahoma closely parallels that of California, starting a little later and very slowly dropping beneath California until now the latter with approximately 6.3 billion barrels, is more than one billion in excess of Oklahoma.

There are so many data available regarding the oil reserves, production history, and decline of discovery rate in the United States that further details are not warranted in this paper. We proceed, therefore, with an endeavor to point out some of the more salient data on the oil reserves of foreign countries and make comparisons with the United States.

Chart No. 3 shows in the panel on the left the percentage of world's reserves as of January 1, 1944, *versus* the percentage of world's production 1943. The percentage of reserves is plotted on the left of the parallel columns as a broken line, the production as a solid line on the right. In preparing this panel the more conservative estimate of indicated reserves was used. The oil reserves of many countries are so small they had to be combined on this chart, but they are discussed in connection with a tabulation which follows. Some pertinent comparisons may be drawn from this chart. The United States has less than 40 per cent of the world's estimated reserves but produced 66 per cent of the total indicated production of the world for 1943. Furthermore, as shown later, our areas favorable for oil accumulation have been and are being explored and exploited to a far greater extent than similar areas in many other parts of the world. In 1941, the last year for which we have reasonably good estimates, the production of oil in the United States was 1,404,182,000 barrels compared with 822,652,000 barrels for all the rest of the world. In 1943, according to the *Oil Weekly*, the estimated total production of petroleum for the world was 2,276,116,000 barrels of which the United States produced more than 1½ billion barrels. In other words, we have in the United States less than ⅖ of the reserves, but we are taking our oil out nearly twice as fast as the rest of the world is taking theirs.

The Persian Gulf (Iraq, Iran, Saudi Arabia, Bahrein, Kuwait, and Qatar) has practically 28 per cent of the world reserves, and during 1943 produced only 116,000,000 barrels, 5 per cent of the world production.

It should be borne in mind that the data on which the available reserves of Russia are based are very meager. Furthermore, our data on the present pro-


UNITED STATES
CUMULATIVE PRODUCTION BY YEARS
CALIFORNIA, OKLAHOMA, PENNSYLVANIA, TEXAS, OTHERS
1890-1943 INCLUSIVE
8-1-44
CUMULATIVE PRODUCTION
JAN.1,1944
CUMULATIVE PRODUCTION IN MILLIONS OF BARRELS
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
TEXAS
CALIFORNIA
OKLAHOMA
LOUISIANA
KANSAS
PENNSYLVANIA
ILLINOIS
WYOMING
ARKANSAS
NEW MEXICO
OTHERS
CUMULATIVE PRODUCTION IN THOUSANDS OF BARRELS
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
1890
1900
1910
1920
1930
1940
1950
TEXAS
OTHERS
CALIFORNIA
OKLAHOMA
PENNSYLVANIA
PENNSYLVANIA
CHART 2

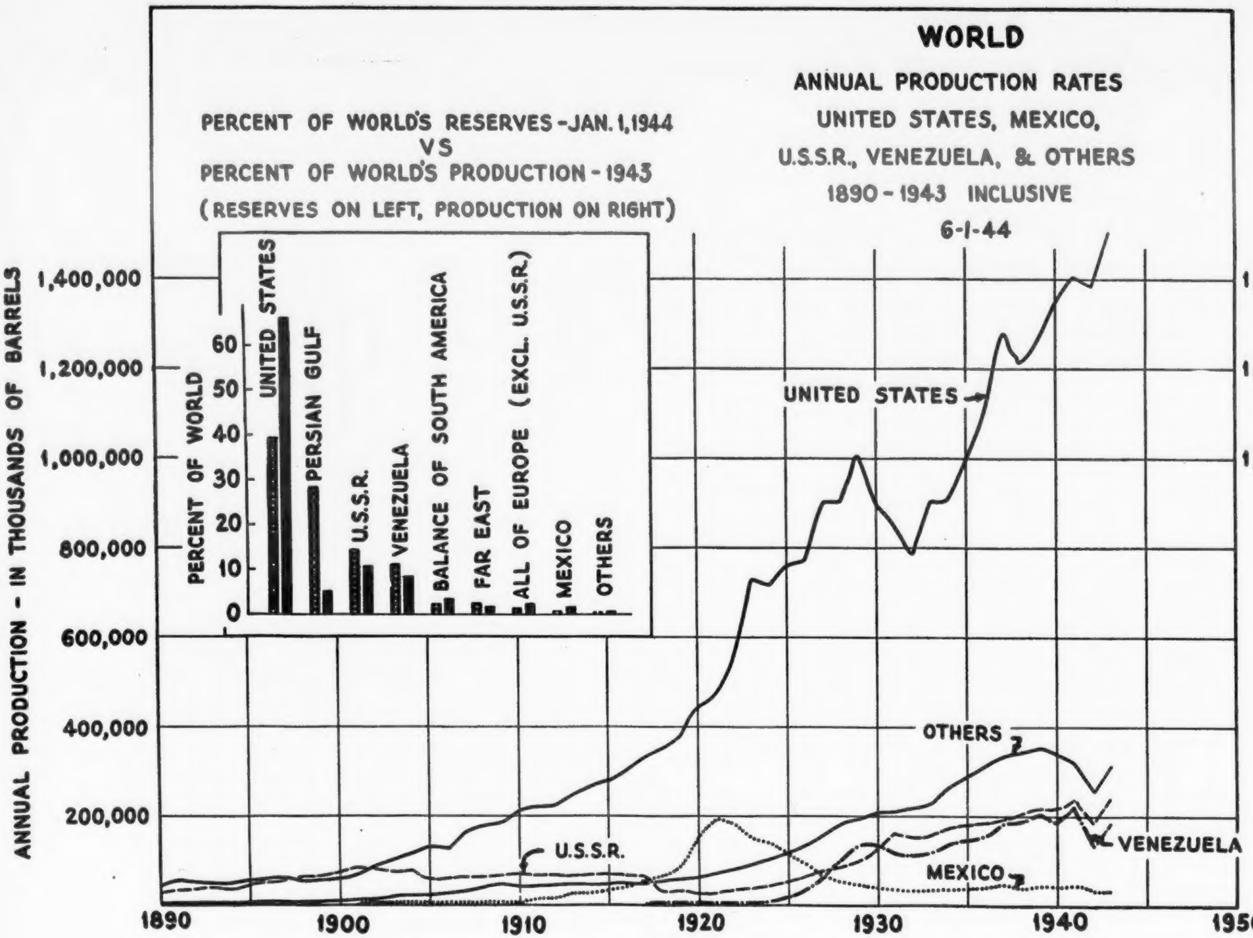

WORLD
ANNUAL PRODUCTION RATES
UNITED STATES, MEXICO,
U.S.S.R., VENEZUELA, & OTHERS
1890 - 1943 INCLUSIVE
6-1-44
PERCENT OF WORLD'S RESERVES - JAN. 1, 1944
VS
PERCENT OF WORLD'S PRODUCTION - 1943
(RESERVES ON LEFT, PRODUCTION ON RIGHT)
PERCENT OF WORLD
0
10
20
30
40
50
60
UNITED STATES
PERSIAN GULF
U.S.S.R.
VENEZUELA
BALANCE OF SOUTH AMERICA
FAR EAST
ALL OF EUROPE (EXCL. U.S.S.R.)
MEXICO
OTHERS
ANNUAL PRODUCTION - IN THOUSANDS OF BARRELS
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
UNITED STATES
OTHERS
U.S.S.R.
MEXICO
VENEZUELA
1890
1900
1910
1920
1930
1940
1950

CHART 3

duction are not much more than hearsay. As an example, the American Institute of Mining and Metallurgical Engineers places the 1938 production at 238,150,000 barrels. Most of this production reportably came from the Caspian Basin. The Ural-Volga region was then in the process of being developed, that year's production being estimated at $9\frac{1}{3}$ million barrels. To-day there are stories to the effect that more than half of the Soviet Union's current production is from the great basins far north of the Caspian.

Venezuela rates third place among the oil-producing nations of the world, but takes fourth place in the classification of indicated reserves. As shown in our tabulation as of January 1, 1944, Venezuela has 11 per cent of reserves and 8 per cent of the world production for 1943.

The balance of South America, Mexico, the Far East (which includes the East Indies, British Indies, *et cetera*) and all of Europe (exclusive of Russia) are placed on the chart for comparison with the more favored petroleum-producing nations.

The curves plotted on Chart No. 3 represent the annual productive rates of the United States, the U.S.S.R., Venezuela, Mexico, and all others combined. The annual production rates of the United States compared with all others is strikingly portrayed in these curves. From them alone can be visualized the growth of the petroleum industry and the dominant part of the United States in that industry. A similar chart showing cumulative production by years is even more striking.

The total world production of petroleum minus that allocated to the United States is shown by a circle at the end of the year 1943; it amounted to 785 million barrels.

In the earlier history of petroleum development it is interesting to note that for a period of about 5 years, between 1897 and 1902, the annual production of the U.S.S.R. was slightly in excess of that of the United States. Mexico's yearly production rose rapidly from 1916 to 1922, when it reached a peak of nearly 200,000,000 barrels per year. From there on for the next 7 or 8 years the annual production rate dropped rapidly. This rapid falling off of production is probably attributable to decreasing demand and failure to maintain an adequate discovery rate. Serious labor trouble and expropriation did not strike Mexico until several years later.

Venezuela and the U.S.S.R. show a steady upward trend of production from 1925 to the outbreak of global warfare. The drop in Venezuela at that time was because of the inability to maintain export transportation. Recent reports indicate that the current trend is sharply upward. For the U.S.S.R. we do not have the facts, but there are reports that indicate that outstanding favorable developments have been taking place and that its trend of production is now sharply upward.

Chart No. 4, giving the world cumulative production by years, shows a similar story. The cumulative production for the United States as of January 1, 1944, amounts to 28 billion barrels, while that of the rest of the world is only

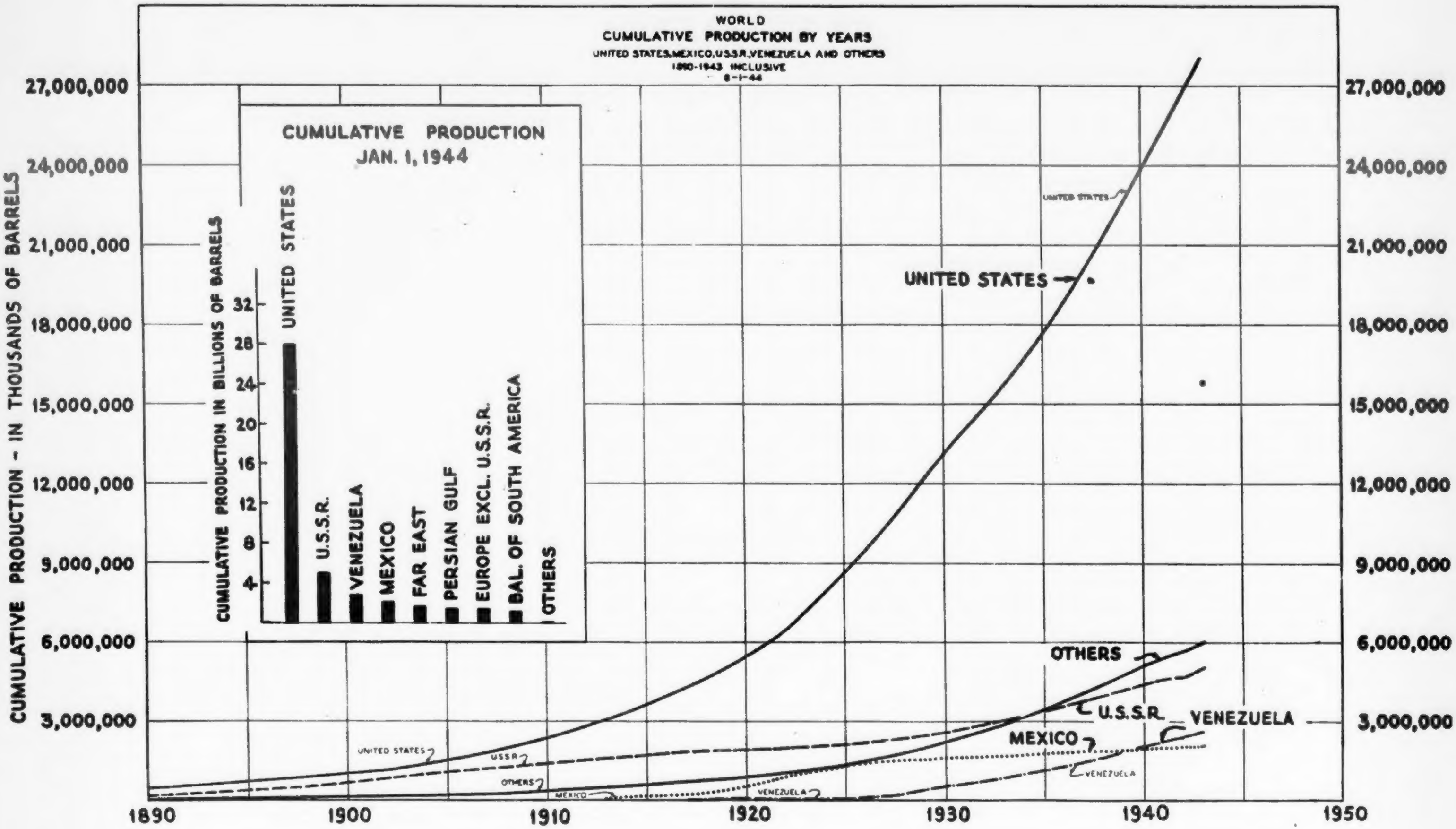

WORLD
CUMULATIVE PRODUCTION BY YEARS
UNITED STATES, MEXICO, U.S.S.R., VENEZUELA AND OTHERS
1890-1943 INCLUSIVE
CUMULATIVE PRODUCTION - IN THOUSANDS OF BARRELS
27,000,000
24,000,000
21,000,000
18,000,000
15,000,000
12,000,000
9,000,000
6,000,000
3,000,000
1890
1900
1910
1920
1930
1940
1950
UNITED STATES
OTHERS
U.S.S.R.
VENEZUELA
MEXICO
CUMULATIVE PRODUCTION
JAN. 1, 1944
CUMULATIVE PRODUCTION IN BILLIONS OF BARRELS
32
28
24
20
16
12
8
4
UNITED STATES
U.S.S.R.
VENEZUELA
MEXICO
FAR EAST
PERSIAN GULF
EUROPE EXCL. U.S.S.R.
BAL. OF SOUTH AMERICA
OTHERS

CHART 4

about 16 billion. Taken by countries, both the charts and the curves show the wide divergence between the United States and other major producing countries of the world. Our cumulative is 5.8 times that of the U.S.S.R., our nearest competitor, and nearly 20 times greater than that of the Persian Gulf. It is not at all improbable, however, that when the curtain is finally lowered on the petroleum drama, we shall find that ultimate recoveries from these three great areas will not be far apart.

Present information indicates that our Black Gold was not disseminated equally throughout the world as the rain falls alike upon the just and the unjust. The really great known deposits are concentrated in a relatively few organically rich marine basins, for example, in parts of the United States, the Soviet Union, Venezuela, and the Persian Gulf. This world distribution is paralleled in the United States, where the major part of the past production and present reserves is contained within a few states: Texas, Louisiana, Oklahoma, and California. A million more wells spread over the world may enlarge the picture, but there will still be the highlights and shadows. The history of mining clearly demonstrates that the mineral wealth of the world is not evenly distributed over the face of the globe.

Table I, showing the estimated recoverable crude petroleum reserves of the world, is a compilation of data derived from various sources. The production data (columns A, B, and C) are of course far more accurate than the estimations of reserves (columns D and E) and the order of speculative possibilities (column F).

Columns D and E are estimates of what the writer has termed "Indicated Reserves." Only a few of the reserve estimates could be classed as "Proved" of much the same order of accuracy as those of the United States. The term "Indicated" is therefore used to convey the idea of relative approximation. In a large number of cases the data from which these reserves were compiled varies considerably and two sets of figures were set up, which have been captioned "Conservative" and "Optimistic."

It is believed that in general the crude-oil reserves as set up in this table permit a reasonable placement of the nations in the family of petroleum producers. Column F, the order of speculative possibilities, is based largely on published geological reports and data relative to the existence, character, and size of basins of sedimentary rocks known to be present in the respective countries.

For the reason that the estimated reserves and the productive history and the geology are for most of us so much better known for the United States than for the foreign nations, we can use these data for the United States more or less as a yardstick. The reserves column D for the United States, 20,064 million barrels, is actually not an indicated reserve, but is the A.P.I. Reserve Committee's estimate for January 1, 1944, of the *proved* reserves. Column E for the United States, 25 billion barrels, is a more optimistic indicated reserve, definitely not an inventory of known available oil. It includes reserves from secondary recovery methods amounting to about 3 billion barrels, which were not included in the A.P.I. proved reserve estimates. Also, estimates of probable reserves or what was classi-

TABLE I

ESTIMATED RECOVERABLE CRUDE PETROLEUM RESERVES

(THOUSANDS OF BARRELS)

AS OF JANUARY 1, 1944

	A	B	C	D	E	F
	PRODUCTION DURING		CUMULATIVE PRODUCTION TO JAN. 1, 1944	INDICATED RESERVE		ORDER OF SPECULATIVE POSSIBILITIES
	1941 (a)	1943 (a)		CONSERVATIVE	OPTIMISTIC	
UNITED STATES	1,404,182	1,503,427	28,099,374	20,064,162	25,000,000	II
CANADA	10,125	9,958	94,333	140,625	200,000	IV
MEXICO	43,837	34,500	2,104,487	413,270	675,000	III
SUBTOTAL NORTH AMERICA	1,458,144	1,547,885	30,298,194	20,618,057	25,875,000	
COLOMBIA	24,553	13,750	325,071	408,584	500,000	III
VENEZUELA	223,784	187,000	2,620,087	5,720,913	6,250,000	II
TRINIDAD	21,211	25,000	268,994	291,110	350,000	VI
ARGENTINE	21,763	23,500	293,905	288,156	325,000	IV
BOLIVIA	230	2,246	4,242	48,004	60,000	IV
ECUADOR	1,557	2,000	30,389	20,094	25,000	IV
PERU	11,922	14,000	301,657	153,343	170,000	VI
SUBTOTAL SOUTH AMERICA	305,020	267,496	3,844,345	6,930,204	7,680,000	IV
BAHREIN, KUWAIT, QATAR, SAUDI ARABIA	12,665	14,500	86,993	3,147,486	4,000,000	I
IRAN	64,000	78,000	1,223,832	6,380,000	7,000,000	I
IRAQ	12,650	23,500	238,493	4,820,000	6,000,000	I
SUBTOTAL PERSIAN GULF	89,315	116,000	1,549,318	14,347,486	17,000,000	
U.S.S.R. (RUSSIA)	238,150	240,000	5,065,539	7,361,250	8,500,000	I
ALBANIA	1,381	1,100	7,968	12,460	21,000	V
AUSTRIA	692	800	4,302	7,236	10,000	IV
CZECHOSLOVKIA	109	125	2,901	1,662	8,000	V
FRANCE	479	600	12,718	4,550	5,600	
GERMANY	4,438	6,500	120,599	57,880	83,000	V
HUNGARY	2,474	5,000	16,739	50,261	75,000	IV
ITALY	46	35	2,893	1,152	1,500	V
POLAND	3,319	3,500	272,914	39,490	44,000	V
ROUMANIA	38,147	42,000	1,032,140	481,671	525,000	IV
SUBTOTAL EUROPE	51,085	59,660	1,473,174	656,362	773,100	
NETHERLANDS EAST INDIES	53,704	20,000	1,064,141	852,768	1,175,000	II
SARAWAK & BRUNEI	6,864	3,000	113,532	66,140	75,000	VI
BRITISH INDIA & BURMA	10,032	4,000	320,940	110,384	125,000	V
JAPAN	2,659	3,500	91,709	23,890	25,000	VI
SAKHALIN	4,000	5,000	49,240	46,000	56,000	VI
SUBTOTAL FAR EAST	77,259	35,500	1,639,562	1,099,182	1,456,000	
CHINA	OTHERS	780 (b)	OTHERS	10,000	20,000	III
EGYPT	7,659	8,800	68,021	69,947	75,000	IV
OTHERS	204	295	3,385	3,033	5,000	VI
WORLD TOTALS	2,226,836	2,276,116	43,941,538	51,095,521	61,384,100	

(a) Oil Weekly with exception of United States, 1943.

(b) Oil and Gas Journal.

SAN FRANCISCO, CALIFORNIA - MARCH 4, 1944

fied by W. B. Heroy, former director of the Division of Reserves of the Petroleum Administration for War, as "Maximum possible (sum of the proved reserves, plus reasonable, but optimistic estimates of unproved reserves)." It may be that a part of the U.S.S.R. reserves of 8.5 billion barrels should go in this classification.

The more optimistic figure for Canada, 200 million barrels, includes the 100 million or more barrels estimated for the Fort Norman district; a total of 140 million for Canada is a better figure.

Mexico's reserve of 400 million looks reasonable on the basis of the last 2 years of production, but 675 million may be on the high side.

The South American countries had a production for 1943 of about 267 million barrels. Their reserves (column D) total 6,930 million and appear large on basis of performance, but their production has been low due to restrictions on outlet. Venezuela, moreover, at present completely dominates all of South America and has several relatively new major fields which are as yet only partly developed.

Production from the countries surrounding the Persian Gulf (Iraq, Iran, Saudi Arabia, and Bahrein) is controlled by their very limited available outlets. Kuwait and Qatar have partly developed fields of high potentialities, but no outlet. The opening during 1943 of the northern leg of the Iraq pipeline increased the productive outlet from 40,000 barrels per day in 1942 to 75,000 per day in 1943. Last year's total production, however, 27,375,000, represents only a very small percentage of that country's capacity to produce from present fields.

Similarly in Iran, Saudi Arabia, and Bahrein the current production is no criterion of the capacity to produce, or of the amount of known reserves. The big refinery at Abadan, near the head of the Persian Gulf has a capacity of 180,000 to 200,000 barrels per day. The refinery on Bahrein Island, about 35,000 per day. Refined products, plus some crude, making a total ranging from 230,000 to 245,000 barrels per day, represents the current supply of petroleum, all of which is taken out of the Persian Gulf by tankers. The total daily production required to supply the limited outlets of the Persian Gulf basin is so small that the reserves credited to the countries surrounding that basin look fantastically large.

The western side of the Persian Gulf, including Kuwait, Saudi Arabia, Bahrein Island, and Qatar, have indicated reserves ranging from 3,147,000,000 barrels to 4 billion barrels. Some recently published estimates are four or five times greater. Iraq estimates range from 4,820,000,000 to 6 billion and Iran from $6\frac{3}{4}$ to 7 billion barrels, making a total indicated reserve, let us say, of 15 to 17 billion barrels for the Persian Gulf basin. Furthermore, the Persian Gulf basin, as mentioned later, has the highest degree of speculative possibilities of any equally well known region in the world.

It is but a fair question to raise—what data are there to support the setting up of such large reserves? The answer is to be found in the enormous size of some of the productive structures and the thickness and permeability of the produc-

tive zones. A few examples from Iran and Iraq[5] suffice. One of the older fields in Iran, known as Masjid-I-Sulaiman, is an elongate anticline, 17 miles long and 4 miles wide, containing 45,000 acres. It has 2,200 feet of closure above the water-oil contact. Production comes from permeable and fractured Asmari (Miocene) limestones 900 feet thick; the upper 400 feet are the more porous. The oil has a paraffine base and an API gravity of 37.6° and comes from depths between 2,000 and 3,000 feet.

The Haft Kel field was drilled in 1923 and it began to produce in 1929. It is an elongate closed dome of 50 square miles. The structure is similar to Masjid-I-Sulaiman, but a little deeper. Wells are reported to produce as high as 40,000 barrels per day against a back pressure of 600 pounds per square inch.

One of the more recently developed fields in Iran, located about 150 miles east of the head of the Persian Gulf, is reputed to have an extent of 100 square miles and to have a reserve of 3 to 4 billion barrels. According to report, the No. 3 well in the field produced 33,000 barrels per day against a flow-pressure of 850 pounds per square inch. The oil is produced from the porous Asmari limestone, at the depth of about 4,000 feet.

One of the well known fields in Iraq is at Kirkuk, the western terminus of the Iraq pipeline. According to R. H. King, there are three domes on the Kirkuk anticline. The presently productive parts of two of these—Baba Gurga and Avanah—are continuous more than 50 miles in length, on a structure 75 miles long. Here also, the producing formation is the very porous Asmari limestone, the depth averaging between 2,100 and 2,200 feet. The gravity of the oil is 30°+ API.

It is reported that it is only necessary to flow 14 wells to maintain the 85,000 barrels per day capacity of the pipeline.

In Saudi Arabia, Bahrein, Kuwait, and Qatar, salt domes and structures of great size have been mapped and only a few of them partly developed. Flowing wells of the same order of productivity as those of Iraq and Iran are not uncommon. The productive formations are for the most part older in geologic age than the presently productive Asmari limestones of Iraq and Iran. However, deeper productive formations are known to occur in both the latter countries.

The indicated reserves for the U.S.S.R. have already been mentioned. Actually, we do not know much about them. In 1942, the writer made an estimate based on published production records, and some more or less authentic geological data, also published. This estimate of approximately 5½ billion barrels was of the same order of magnitude as that published by Garfias.[6]

The reserve estimates presented by J. Terry Duce[7] before the O'Mahoney

[5] R. H. King, *Petroleum Engineer* (October, 1938).

[6] V. R. Garfias and R. V. Whetsel, "Estimate of World Oil Reserves," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 132 (1939), pp. 608–10. (*Petroleum Development and Technology*, A.I.M.E. Petroleum Division.)

[7] J. Terry Duce, *Hearings U. S. Senate*, S.1243 (1943).

Committee, and by Professor I. Gubkin,[8] which range from $7\frac{1}{3}$ to $8\frac{1}{2}$ billion barrels now appear more closely to portray the U.S.S.R.'s position with respect to the petroleum reserves of the world.

In Europe outside of the U.S.S.R., the only nation with known reserves of importance is Roumania. The $\frac{1}{2}$ million barrels assigned to Roumania may be on the conservative side. Just prior to the global war it was reported that Roumania was developing some interesting incompletely tested prospects. A similar statement should also be made for Austria and Hungary.

The countries under control of the Axis in Europe, including France and Italy, were credited with a production of 51,085,000 barrels for the year 1941. According to recently published statistics in the *Oil Weekly*, 1943 production for these Axis-controlled countries amounts to 59,660,000 barrels. Some unconfirmable statements indicate an even higher yearly production. Indicated reserve estimates for these countries range from 656 to 773 million barrels. By using the reported yearly productions as a yardstick, a reserve of 700 million barrels would not appear out of line.

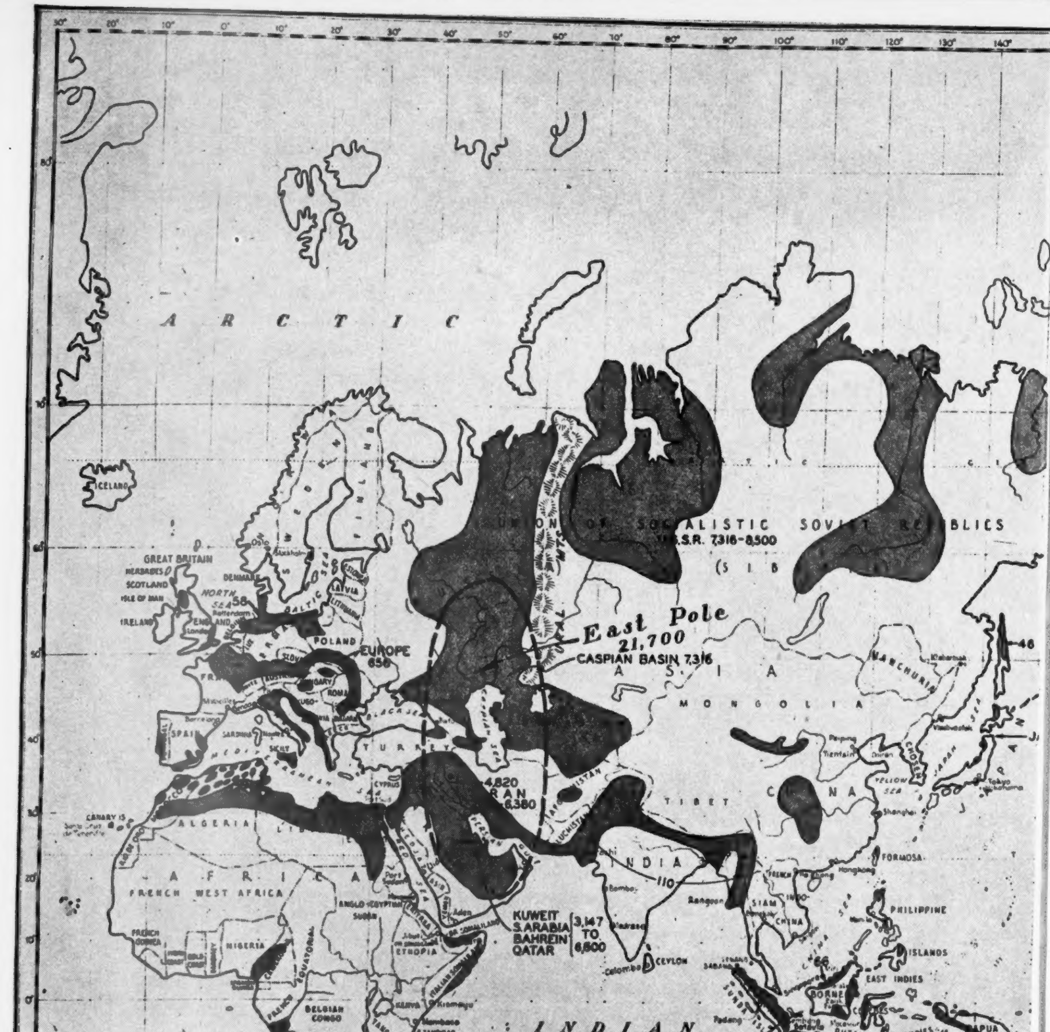
In addition to the natural crude production, the Axis powers have developed a large production of synthetic fuels derived mostly from the hydrogenation of coals. Their gasolines as well as some of the other products are said to be of excellent quality.

By far the largest known reserves of the far eastern countries are in the Netherlands East Indies. If we include the fields of Sarawak and Bruni of North Borneo with the Netherlands East Indies (columns D and E), the indicated reserves of the East Indies total in round figures a little more than a billion barrels, as compared with about 200 million from the presently known fields of India, Burma, Japan, and China.

Some interesting developments, however, regarding which we have only little authentic information, are taking place in China, in Northwest Kansu, on the southern edge of the Gobi desert where an oil field near Yumen is reported as being productive up to 3,000 barrels per day.

Attention has been directed to estimates intended to show the comparative magnitude of the petroleum reserves of various countries of the world. An inspection of a map of the world shows how they are distributed over the face of the globe. Figure 1 is a Mercator projection map of the world showing petroliferous areas. These are the shaded areas on the map, some of which, such as those in the United States, have been extensively explored and developed. In others, developments have progressed to a degree which permits making reasonably good estimations of large petroleum reserves, and in the third class are extensive marine sedimentary basins known to contain oil, but in which exploration and exploitation have been very limited. Unfortunately for us, the last two classes are for the most part outside the limits of the United States.

[8] I. Gubkin, *Petroleum World* (1939?).



ARCTIC
ICELAND
GREAT BRITAIN
HEBRIDES
SCOTLAND
ISLE OF MAN
IRELAND
ENGLAND
London
Rotterdam
NORTH SEA
58
DENMARK
BALTIC SEA
LATVIA
LITHUANIA
FINLAND
Oslo
Stockholm
POLAND
EUROPE
656
SPAIN
SARDINIA
SICILY
MEDITERRANEAN SEA
BLACK SEA
TURKEY
CYPRUS
CASPIAN SEA
UNION OF SOCIALISTIC SOVIET REPUBLICS
U.S.S.R. 7,316-8,500
East Pole
21,700
CASPIAN BASIN 7,316
ASIA
MONGOLIA
MANCHURIA
Khabarovsk
Vladivostok
CHOSEN
JAPAN SEA
YELLOW SEA
Tokyo
Yokohama
Peiping
Tientsin
Shanghai
TIBET
CHINA
FORMOSA
Hongkong
4,820
IRAN
6,380
KUWEIT
S.ARABIA
BAHREIN
QATAR
3,147
TO
6,800
INDIA
110
Bombay
Madras
CEYLON
Colombo
Rangoon
SIAM
PHILIPPINE
ISLANDS
EAST INDIES
BORNEO
SUNDA ISLANDS
Padang
Batavia
DUTCH EAST INDIES
PAPUA
EAST INDIES
66
852
918
46
CANARY IS.
ALGERIA
AFRICA
FRENCH WEST AFRICA
FRENCH GUINEA
GOLD COAST
NIGERIA
ANGLO-EGYPTIAN SUDAN
Aden
ETHIOPIA
BELGIAN CONGO
KENYA
Kismayu
Mombasa
Zanzibar
Dar-es-Salaam
TANGANYIKA
ANGOLA
NORTH RHODESIA
ST. HELENA IS.
SOUTH WEST AFRICA
Walvis Bay
UNION OF SOUTH AFRICA
Durban
Cape Town
MADAGASCAR
Tamatave
INDIAN
OCEAN
TROPIC
AUSTRALIA
Perth
Melbourne

FIG. 1

GREENLAND
OCEAN
ALASKA
BERING SEA
ALEUTIAN ISLANDS
HUDSON BAY
CANADA 141
DOMINION OF CANADA
NEWFOUNDLAND
UNITED STATES 20,064
JAPAN 24
PACIFIC
ATLANTIC
New Orleans
GULF OF MEXICO
MEXICO 413
WEST INDIES
HAWAIIAN ISLANDS
CARIBBEAN SEA
West Pole 20,832
CENTRAL AMERICA
TRINIDAD 291
VENEZUELA 5,720
COLOMBIA 408
ECUADOR 20
PERU 153
BOLIVIA 48
EQUATOR
OCEAN
SOLOMON ISLANDS
SOUTH AMERICA
BRAZIL
TAHITI IS
CAPRICORN
NEW CALEDONIA
Sydney
Auckland
NEW ZEALAND
TASMANIA
ARGENTINA 288
OCEAN
THE WORLD
ON MERCATOR'S PROJECTION
SCALE
LAND MILES AT THE EQUATOR
SHOWING PETROLIFEROUS AREAS
RESERVES FIGURES IN MILLIONS OF BARRELS

FIG. 1

The reserve estimates of areas now known to contain the major reserves of the world have been placed on the map. Nearly on the opposite sides of the earth, we find in the Western Hemisphere the prolific oil fields of the United States, Mexico, Venezuela, and Colombia, and in the Eastern Hemisphere the great reserves of the countries which make up the Persian Gulf Basin and the Caspian Basin of the U.S.S.R.; the latter includes reserves estimated to be 21 to 25 billion barrels while the former, within which the size of the reserves are better known, contains 27 to 30 billion barrels.

On the map are inscribed two ellipses of equal size. One includes the geologically young crustal depressions or marine basins tributary to the Gulf of Mexico and to the Caribbean Sea. The other ellipse surrounds the basins of the Persian Gulf and the Caspian Sea. These ellipses more or less outline what Wallace Pratt calls the "Petroleum Poles of the Earth." The indicated reserves for these two poles or ellipses are approximately the same. Together they account for more than 90 per cent of known reserves of the world. Production from the Eastern Poles including all of Russia (since there are no data available to permit segregating the Caspian Basin from the rest of Russia) is only 16 per cent of that of the Western Pole. Competent observers have recently estimated that the reserves of the Persian Basin alone may be as large as those of the United States and Harold L. Ickes, president of the Petroleum Reserves Corporation, states[9] that the proved and indicated reserves of Kuwait and Saudi Arabia are between 13 and 14 billion barrels. It is, therefore, apparent that for the future the reserves of the Old World may well dominate those of the New.

These great reserves at the "Petroleum Poles" of the earth have a geological significance. They are found to occur in four large essentially marine basins or geologically young crustal depressions. Those of the Western Hemisphere are tributary to the Gulf of Mexico and the Caribbean Sea, while those in the Near East comprise the basins of the Caspian Sea and the Persian Gulf. One other crustal depression, that of the East Indies, containing an estimated billion barrels of reserves, might be added. The remainder of the presently known reserves are found scattered over the globe, for the most part in small restricted basins.

The reservoir rocks responsible for the major part of the oil in these five great structural depressions are composed for the most part of Cenozoic and Mesozoic formations. In fact the preponderance of the known oil in the earth is young geologically. It has been estimated that less than half of the cumulative production of the United States was from Paleozoic rocks and that our present proved reserve of 20 billion barrels is approximately 25 per cent in the old rocks and 75 per cent in the Mesozoic and Cenozoic. It is reported by good authorities that less than 2 per cent of the past production and known reserves outside the United States is from rocks older in age than the Mesozoic. For the world as a whole 87 per cent of the known reserves are Mesozoic or younger in age.

[9] *Oil Weekly* (March 6, 1944).

It is obviously not the intent of this paper to discuss geology, but to the geologist who wishes to look at the future petroleum prospects of the earth and to speculate on where they may be found, the close relationship of the bulk of the known reserves to great crustal depressions or marine basins containing thick sections of near-shore sedimentary rocks of young geological age is significant.

The order of speculative possibilities of Table I, column F, is based on these speculations.

If we look again at the map of the world a few pertinent comments might be in order before bringing this paper to a close. Compared with the rest of the world the more geologically favorable structures and marine sedimentary basins in the United States have been rather thoroughly combed.

Despite the decline in discovery rates during the past 3 or 4 years, there will be material additions in future years to our proved reserves. These will come through discovery of a decreasing volume from new fields, from extensions of already discovered fields, and as the result of more efficient methods of extraction, including secondary recovery. For these reasons the United States is given as high a rating as II in the order of speculative possibilities.

The petroliferous basins tributary to the Caribbean have within the last few years commenced to come into their own. Venezuela is rated as II and Colombia as III.

The prospective possibilities of Trinidad are known to be limited and a low rating is given for that country. The size and character of the basins of marine sediments for the other countries of South America can hardly be classed as being as good as Venezuela and Colombia; therefore, they are of the order of IV in speculative possibilities.

The great basin of the Caspian Sea that includes the Baku, Grosny, and Maikop fields is fairly well known so far as the older fields are concerned. We know comparatively little of the Ural-Volga region on the north, and the great basins of northern Siberia tributary to the Arctic Ocean are practically *terra incognita*. We do know that they are in part at least petroliferous. Evidences of oil in the form of seepages and favorable geological conditions are reported to extend along the valley of the Lena River for a distance of nearly 2,000 miles. The U.S.S.R. unquestionably deserves the top rating of I.

South of the Soviet Republics in northern China on the southern edge of the Gobi Desert in Kansu, M. H. Bush[10] reports the presence of seepages and a favorable territory 1,800 miles in length warranting prospecting. There are several other great basins in eastern China which will some day claim the attention of the geologist and the geophysicist. In column F, China as compared with Russia should have a lower rating and should be in either the II or III class.

The countries which occupy the Persian Gulf Basin have already been dis-

[10] M. H. Bush, adviser, Kansu Petroleum Administration. Also, *Oil & Gas Jour.*, Mar. 9, 1944.

cussed in some detail. Their presently developed and indicated reserves are enormous. They contain vast areas, undeveloped but favorable for exploration and should be rated in Class I, as high as, if not higher than, Russia.

In the Far East past developments and present information indicate good speculative possibilities for the Netherlands East Indies which merit a rating of II. The other Far Eastern countries are rated V or VI.

The countries of Europe excepting Russia have in general a low rating of IV or V in this rather arbitrary order of speculative possibilities based for the most part on published accounts of the extent, character, quantity, and age of the rocks which make up their basins of marine deposition.

The great crustal depression of the Mediterranean Sea is intriguing and possibly some of the countries bordering thereon should have a higher classification than IV. Theoretically this extensive Mediterranean basin should be favorably comparable with some of the other great crustal depressions of the world, rich in petroleum, but this problem may be left to others more familiar, than is the writer, with the geology of northern Africa and southern Europe.

The preparation of a paper of this kind and compilation of requisite statistical data entailed the reading and analysis of published articles, reports, and documents of a large number of authors. To them all credit is due; particularly to Wallace E. Pratt whose recent lectures and articles have been much quoted.

Data and statistics dealing with production, production history, and general information relating to extent and development of oil fields of the world are simple and devoid largely of controversial opinion. The problems of petroleum reserves and future prospects are another matter. There are no accepted definitions for the various kinds of reserves and no standard methods for their calculation. Until wells are drilled and tests made, opinions about the merits of prospective areas can be widely divergent. So, there have developed two or more schools of thought regarding the magnitude of the reserves and the quantity of oil in the earth yet to be discovered. There has recently been much published controversy regarding these questions within the United States and it is not surprising that the public at large, and many within the oil industry, are often confused over the divergent views of the optimists and pessimists. The optimists are those who look at the doughnut, the pessmists those who see only the hole in the doughnut.

The quantity of oil in the earth that yet remains to be discovered—no man knows. Unfortunately there is no known set of criteria by which such estimates may now be made that can not be torn to shreds. Many large deposits of petroleum will undoubtedly be found. The rate of discovery of new oil in the United States has been declining during the past few years. Possibly we are in the trough of similar cycles out of which in the past we have successfully climbed. We may again climb upward, but let us not fool ourselves by over-optimism. The record of accomplishment of the petroleum industry in the United States is of the highest order and if free and independent industry is permitted the right

of way, unhampered by Government control, but, *in lieu* thereof, aided by a sympathetic understanding of their problems, the petroleum independence of the United States will be preserved.

In years to come, synthetic fuels may play an important rôle as a means of maintaining national petroleum independence. Our ultimate supplies of liquid fuels from coal and oil shale run into figures which make the national debt look small. What was done by industry in a few years to develop a thoroughly satisfactory supply of magnesium in the United States, that is, establish our magnesium independence, can and will be done by the oil industry to produce synthetic fuels. The success of our synthetic rubber program is perhaps as outstanding as that of the magnesium industry.

All of us probably agree that for the world at large the Age of Oil is with us now, and that the world-wide demands for petroleum and allied products will be far greater after the war than ever before. In order to meet these demands, exploration and exploitation of foreign fields must go forward with ever increasing tempo. We have already combed the prospective areas of the United States with a fine-toothed comb. Our successes have been outstanding. Analogous areas are still awaiting that fine-toothed combing in many parts of the world. Horace Greeley in his day gave good advice when he said "Young man, go West." My suggestion now is "Young Geologist, go Foreign, and be careful to land in the right geological basin."

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DISTRIBUTION OF PETROLEUM IN THE EARTH'S CRUST[1]

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ABSTRACT

The generally accepted theory of origin of petroleum makes thick series of sediments which accumulate on the floors of land-locked seas the most likely environment for the generation of petroleum. Neither the permanent land nor the deep oceans serve so well. Seas of this character have occupied much of the area of the continental shelves in the past, fringing the crystalline shields of the continents and lying between these and the ocean basins proper. But certain parts of the earth's surface have long been particularly favorable for the existence of these "seas in the midst of the land." The present "mediterraneans" or great regions of land-locked seas on earth, lying in the depressed mobile segments between the continents, mark sites where similar seas have endured throughout much of earth history and should, if our theory of the origin of petroleum is correct, constitute first-rate territory in which to search for petroleum.

The principal regions of land-locked seas occupying intercontinental troughs or depressions in the earth's crust are the following.

1. The environs of the Mediterranean, Red, Black, and Caspian seas and the Persian Gulf, occupying the depressed segment between the continents of Africa, Europe, and Asia. In this region the magnificent petroleum resources of the Near and Middle East are now being developed.

2. The environs of the Gulf of Mexico and the Caribbean Sea, lying in the land-locked basin between the continents of North and South America. This region contains the most important petroleum resources so far developed in the Western Hemisphere; Trinidad, Venezuela, Colombia, Mexico, and the Gulf Coast area in the United States.

3. The environs of the shallow island-studded seas which lie between the continents of Asia and Australia in the Far East. Important petroleum resources have already been developed on the islands of Borneo, Sumatra, Java, and New Guinea and much promising territory remains to be explored in this region.

4. The environs of the land-locked Arctic Sea, lying in the north-polar depression between the continents of North America, Europe, and Asia. This region is almost wholly unexplored, but it is characterized throughout by conspicuous surface evidences of petroleum.

The results of widespread inquiry into the occurrence of petroleum in the earth are readily available in reference literature. The late W. A. J. M. van Waterschoot van der Gracht, for example, wrote both of the stratigraphic and geographic distribution of petroleum, as well as of its presence in belts of folded rocks over the earth.[3] Descriptions of petroleum resources by states and countries are so common as to constitute the established pattern for general treatises on the subject of petroleum. The relationship of petroleum accumulations to geologic structure, regional and local, has been perhaps the favorite field of research among petroleum geologists. These aspects of the problem of the distribution of petroleum have been widely discussed. A subject much less frequently commented on is a broad consideration of the relationship of the petroleum-bearing rocks to the earth's crust as a whole. This relationship, the following paragraphs briefly discuss.

Our studies lead us to select as the most likely environment for the generation of petroleum the thick series of sediments and of evaporites, rich in organic matter, which have formed in marine waters in previous geologic cycles. Shallow seas

[1] Presented by title before the Association at Dallas, March 22–23, 1944. Manuscript received, July 17, 1944.

[2] Vice-president, Standard Oil Company (New Jersey).

[3] *The Science of Petroleum*, Vol. I, pp. 58, 63, and 247. Oxford University Press, London (1938).

have occupied much of the area of the continental shelves from time to time in the past, fringing the crystalline shields of the continents and spreading outward into the ocean deeps. But the particularly favorable "seas in the midst of the land," which the petroleum geologist seeks, seem to have characterized certain sectors of the earth's crust throughout much of geologic time.

Of course, factors other than a thick series of organic sediments are essential to the existence of important petroleum resources. Neither petroleum nor the natural reservoirs in which we find it can tolerate too severe induration or metamorphism of the enclosing rocks. The containing rock layers must not be too violently dislocated, broken, or distorted by earth movement subsequent to deposition. Many of our most important accumulations of petroleum are found in the foredeeps of sedimentary basins. Sediments containing natural reservoirs of petroleum often represent the rapid erosional degradation of an adjacent mountain arc fringing the very margin of the basin. Orogenic hinge lines, unconformities, overlaps, strand lines, reefs, and bars are important agencies in the accumulation of petroleum.

All these factors command attention in the search for petroleum, but the primary *desideratum* continues to be a thick marine series of rapidly accumulated, clastic or, saline sediments, rich in organic matter.

Some of the present "mediterraneans" of the earth mark sites which, throughout much of earth history, have been covered by land-locked seas. In particular, the depressed, mobile segments of the earth's crust, lying between the great continental masses at their points of near contact with each other, constitute areas of inherent crustal instability which repeatedly in the past have been invaded by shallow seas. Several of these intercontinental depressions are identified with the extension of Chamberlin's "yield-tracts" across the "fulcrum zone" of the juvenile earth.[4] If our theories of the origin of petroleum are correct, these regions of persistent unrest have the fundamental character which makes them a favorable environment for rich petroleum resources.

From the surrounding lands, torrents of clastic sediments poured into the waters which filled these depressions. Under the prevailing near-shore and shallow-water conditions, marine life multiplied, yielding a rich organic residue to be entombed in the rocks that formed on the sea floor. As the load of sediments accumulated, the sea floor in these delicately balanced zones subsided, permitting continued deposition and the accumulation of a thick series of rock layers. This same crustal mobility made for ready emergence and folding, as well as submergence. As a result of such compensating movements, foredeeps developed in the basins of deposition, flanking elevated lands on the adjacent shore, and, elsewhere, occasional barriers rose to restrict the flow of the tides from the deep ocean into the land-locked seas. During periods of aridity, these barriers caused extensive dessication and consequent precipitation of evaporites in the seas they cut off.

[4] T. C. Chamberlin, *The Origin of the Earth*, pp. 207–10. University of Chicago Press (1916).

These are the conditions which we believe contribute largely to the origin and accumulation of petroleum and the regions in which these conditions have prevailed during previous geologic cycles should constitute promising petroleum provinces.

If we turn to an inspection of the earth's physiographic lineaments, we are confronted with four principal regions of modern land-locked seas occupying inter-continental troughs or depressions. And casual inquiry at once reveals that earlier geologic cycles record the presence of similar seas in the same general positions. These regions of persistent inter-continental mediterraneans are the following.

1. The environs of the Mediterranean, Red, Black, and Caspian seas and the Persian Gulf, occupying that uneasy sector of the earth's crust which is caught between the continents of Africa, Europe, and Asia. In large part below sea-level to-day, this "Caspio-Mediterranean series of depressions" is subtended by the two legs of "the African yield-tract" and their northward "angulations" along the borders of the "Eurafrican quadilateral" of Chamberlin's infantile earth. Throughout Mesozoic and Cenozoic time, at least, land-locked seas in this region have received immense volumes of clastic sediments and chemical precipitates, rich in organic content. It is hardly necessary to add that in this mediterranean region of the Old World are the tremendous petroleum resources of the Near and Middle East, which, as we have recently come to realize, easily surpass in potential volume any others on earth.

2. The evirons of the Gulf of Mexico and the Caribbean Sea, the land-locked basin lying between the continents of North and South America. Again, parallel yield-tracts, extending northwestward from the eastern tip of Brazil to Florida and from the western bulge of northern South America through Central America and Mexico, respectively, delimit this intercontinental trough. In the Mesozoic and Cenozoic seas which once filled this depression were deposited the sediments in which are contained the most important petroleum resources, known and prospective, of the New World. They are second only to the resources of the Near and Middle East.

3. The environs of the shallow, island-studded seas which spread over the unstable region lying between the continents of Australia and Asia in the Far East. This basin, out of which rises the East Indian archipelago, including the great islands of New Guinea, Borneo, Sumatra, and Java, is also bounded laterally by yield-tracts in the framework of the embryonic earth as conceived by Chamberlin. One of these lines trends northwestward from New Zealand through New Guinea and the Philippines; the other extends from Australia through Sumatra. Important petroleum resources are already known to exist in the larger islands of this region and additional discoveries may confidently be anticipated as exploration, now only in its initial stages, progresses. This region promises to serve the Orient as one of the earth's most important petroleum provinces.

4. The environs of the land-locked Arctic Sea, lying in the north-polar de-

pression and surrounded by the continents of North America, Europe and Asia. This region is almost wholly unexplored, but already a sizeable oil field has been developed at Fort Norman on the lower Mackenzie River in northwest Canada, and impressive seepages of oil and gas have been observed at numerous places along the Arctic Coast in Northwest Canada, in Alaska and in Siberia, over a zone more than 4,000 miles in length.[5] It is not unlikely that the Arctic will contribute significantly to the petroleum supplies of both hemispheres as civilization continues to move northward over the long future.

American maps commonly designate the waters surrounding the North Pole as the Arctic Ocean. These waters are in fact a land-locked sea—the North Polar Sea, a part of the Arctic Mediterranean[6]—into which the streams draining three great continents have been discharging sediments throughout most of geologic time.

The low temperatures which prevail in the Arctic regions to-day are, of course, of too brief duration to have affected the life of earlier geologic cycles. Cenozoic and Cretaceous palms flourished far north of the Arctic Circle. Moreover, it is by no means certain that Arctic temperatures seriously depress the level of vital activity in marine waters. "Many observations indicate a higher rate of organic production in the high latitudes than in the tropics."[7] In the springtime, there is a "great flare of diatom production" in the Antarctic and on the sea floor a broad band of diatomaceous ooze encircles the Antarctic Continent.

There are other important petroleum provinces on earth. The epi-continental and marginal seas that have advanced across the continental shelves and spread over the continents themselves in past geologic cycles have left us a magnificent heritage of petroleum. Our own prolific Mid-Continent region and the tremendous petroleum resources of California are outstanding examples. There are other regions of land-locked seas, such as the lands surrounding the Sea of Japan, the Sea of Okhotsk, the North Sea, and the Baltic Sea, which may eventually add greatly to our reserves of petroleum.

It will be objected, in criticism of the thesis presented in this paper, that the prominent mediterranean regions of the earth have suffered profound movement and distortion. In them volcanism has manifested itself persistently and has disturbed the processes and conditions requisite to petroleum genesis and accumulation. Nevertheless, it will be recognized that the sectors of the earth's crust fundamentally favorable for petroleum are the four great inter-continental depressions herein defined.

[5] One of the earliest historical references to the occurrence of petroleum in the Arctic is the record of the observations of the pioneer explorer, Sir Alexander Mackenzie on his early discovery and navigation of the great river which came afterward to bear his name, at a time, more than 100 years ago, when petroleum was such a novelty that we spelled it quaintly "petrolium."

[6] H. V. Sverdrup, Martin W. Johnson, and Richard H. Fleming, *The Oceans*, p. 13. Prentice-Hall, New York (1942).

[7] *Ibid.*, p. 941.

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THEORY OF ORIGIN AND ACCUMULATION OF PETROLEUM[1]

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ABSTRACT

Organic débris either of animal or plant origin when laid down in sediments under saline conditions is converted by the action of bacteria into a relatively stable product termed neokerogen. During the process of compaction of the sediments, the skin-frictional heat generated by the sedimentary particles sliding over one another decompose the neokerogen into gases and liquids, a considerable proportion of which are unsaturated. These decomposition products travel as films on the surface of the particles. When these films migrate into a more porous zone, the increase of vapor pressure occasioned by passing from the capillary through which the film has been moving into the porous zone results in the liberation of gases which accumulate in the porous zone. Here the gases and the liquids associated with them are converted into petroleum by the catalytic action of the oxide surfaces of the sediments acting through geologic time.

The mechanism of the formation and accumulation of petroleum has been the subject matter of many papers.[3] The principal factors considered in these papers are: (1) material from which petroleum is formed, (2) method of formation of petroleum from the source material, and (3) mechanism of the accumulation of petroleum. Details of the various theories may be found in the literature. The weight of opinion supports the idea of the formation of petroleum from organic matter. Likewise, present-day opinion favors a lower temperature for the transformation of the source material into petroleum than was deemed feasible when the earlier theories were formulated.[4] There are two schools of thought with reference to the mechanism of the accumulation of petroleum: one advocating the long-distance migration of the oil into the pool, and the other favoring the formation of oil close to the pool in which it is found. Recent developments in physical chemistry provide well established principles which, when applied to the problem of the formation and accumulation of petroleum, furnish a possible answer to some of the phases of the problem. That the application of these principles to this problem has a sound basis is apparent when consideration is given to the facts that the transformation of the source material into petroleum must occur as the result of chemical action, and that large surfaces are associated with the source material in the sedimentary rocks.

PETROLEUM SOURCE MATERIAL

Assuming that petroleum is formed from organic débris, we may ask, what is the nature of this débris and from what type of organic matter did it originate; plant, animal, or both? Involved in this subject is the relation of the kerogen of oil shales to the source material from which petroleum is formed in nature. A

[1] Manuscript received, May 19, 1942; revised, July 19, 1944.

[2] The Fort Worth Laboratories.

[3] *Report of a Conference on the Origin of Oil*, Amer. Assoc. Petrol. Geol. (1941). Bibliography, pp. 72–78.

[4] *Ibid.*, pp. 19–21.

consideration of the factors concerned in the manufacture of sauerkraut and pickles furnishes a basis for formulating a theory of the method of forming the source material of petroleum and the kerogen of oil shales from organic débris.

At the conference on the origin of oil conducted by the research committee of the American Association of Petroleum Geologists, held in Houston, Texas, April 5, 1941, the writer suggested that the formation of kerogen was similar to the action involved in the formation of sauerkraut and pickles.[5] Because of the brine conditions under which sauerkraut and pickles are processed, the types of bacteria present cause only a partial decomposition of the cabbages and cucumbers, leaving a comparatively stable residue under the conditions existing. The environment controls the types of bacteria which will flourish.

The types of bacterial growth present in the formation of sauerkraut are dependent on the concentration of the salt used and that of the acid produced by the fermentation.[6] The acidity of the kraut juice affects its pH and therefore also affects the bacterial life present.[7] This fact is of importance when the formation of the petroleum source material deposited in sediments which ultimately form shales and limestones and similar rocks is considered. Almost 100 per cent of the gases formed by the fermentation of cabbage to form kraut is carbon dioxide.[8] Under the anaerobic conditions occurring in the fermentation of cabbage, the sugars of the cabbage mainly are attacked, the proteins and other constituents being little affected.[9]

In the preparation of pickles, the cucumbers are immersed in much more concentrated brines than are used for manufacturing sauerkraut. The salt concentration in pickles may be as high as 20 per cent (200,000 p.p.m.).[10] The concentration of the brine used in the preparation of pickles more nearly resembles that which is encountered in nature in the formation of petroleum source material from organic débris deposited in closed basins. Some bacteria actually live on dry salt crystals and will not grow in media containing less than 16 per cent salt.[11] Not only does the concentration of the brine affect the bacterial flora, but also the composition of the salts forming the brine influences the bacterial flora.[12]

In nature, the organic débris deposited in sediments in seas, which sediments ultimately form shale, limestone, or dolomite, is subjected to bacterial

[5] *Ibid.*, pp. 32–33.

[6] Carl S. Pederson, *New York State Agri. Exp. Sta. Bull. 595*, p. 14.

[7] *Ibid.*, *Bull. 168*, p. 18.

[8] Preuss, Pederson, and Fred, *Indus. Eng. Chem.*, Vol. 20, p. 1187.

[9] Carl S. Pederson, *New York State Agri. Exp. Sta. Bull. 595*, p. 10.

[10] Fabian Bryan and Etchells, "Experimental Work on Cucumber Fermentation," *Michigan Agri. Exp. Sta. Tech. Bull. 126*, p. 7.

[11] W. W. Browne, "Halophilic Bacteria," *Proc. Soc. Exper. Biol. and Med.*, Vol. 19 (1922), pp. 321–22.

[12] Fabian Bryan and Etchells, *op. cit.*, p. 8.

action in the presence of brine, resulting in a stable condition of the organic matter similar to that which occurs in the formation of kraut and pickles. This relatively stable organic matter resulting from bacterial action is believed to be the source material from which petroleum is formed in a manner subsequently described in this article. This altered condition of the organic débris is termed neokerogen, because during geologic time under certain conditions it becomes the kerogen[13] of oil shales. While the composition of the neokerogen is dependent on a number of factors, this material can probably be formed from any organic débris, vegetable or animal. The factors which affect the final composition of the neokerogen seem to be: (1) the composition of the original organic débris, (2) the composition and concentration of salts in the brine, which affect the types of bacterial life, and (3) the composition of the sediments, which affects the pH and surface phenomena.

Where organic débris is deposited in sediments which ultimately become limestone or dolomite, the bacterial flora will be different from that occurring in sediments which ultimately become shale. In limestone- or dolomite-forming sediments, the acids liberated by the fermentation will be neutralized by the sediments. The carbon dioxide formed will dissolve calcium and magnesium carbonates, causing porosity.[14] Calcium bicarbonate is less soluble than magnesium bicarbonate, and, therefore, in dolomitic limestone, the porosity will be greater than in non-dolomitic limestone. This porosity constitutes traps in which the petroleum can accumulate. A sea having a high concentration of magnesium salts is required to convert limestone to dolomite on a large scale.[15] Thus, when organic débris is deposited in sediments which become converted to dolomite, the bacterial flora is different from that occurring in sediments which become limestone because of the difference in concentration and composition of the salts present in the sea forming dolomite compared with the sea depositing limestone. The bacterial decomposition of the organic débris will be more nearly complete in sediments which become limestone, because of greater bacterial activity caused by the lesser salt concentration, than in sediments which become dolomite; and, therefore, the amount of neokerogen formed will be greater in dolomite than in limestone. For this reason, other factors being the same, for the same amount of organic débris deposited in sediments which become dolomite compared with sediments which become limestone, the dolomite-producing sediments will contain more neokerogen.

[13] The writer is aware of the multitudinous concepts of the term kerogen existing in the minds of its numerous students. Since, however, these concepts are not pertinent to this particular phase of the problem of the origin and accumulation of petroleum, they are not discussed here.

[14] Walter R. Berger and Ralph H. Fash, "Relation of Water Analyses to Structure and Porosity in the West Texas Permian Basin," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), p. 877.

[15] Francis M. Van Tuyl, "The Origin of Dolomite," *Iowa Geol. Survey*, Vol. 25, Annual Rept., 1914, pp. 251–422.

When organic débris is deposited in fresh water, bacterial action is so vigorous that the destruction of the organic material is relatively complete and, hence, no appreciable amount of neokerogen will remain. Therefore, commercial oil pools are not likely to be formed from organic matter deposited in fresh water. Where comparatively fresh water is found associated with oil in commercial quantities, the fresh water has probably replaced the connate water originally present.

Applied principles of physical chemistry given in the following paragraphs provide a basis for a theory of the formation of petroleum from neokerogen and the accumulation of petroleum in pools.

SKIN-FRICTIONAL HEAT

When two solids slide over one another, heat is generated in proportion to the force with which the solids are held in contact with each other. The major heat effect may occur only in the surface molecules without appreciably raising the temperature of the main body of the solids. The formation of this high skin temperature in the surface molecules is well illustrated by the following statement by Adam.[16]

> But there is now little doubt that, when a fully amorphous, highly polished, surface layer is produced, the surface layers are actually liquefied by heat momentarily, through the friction produced by the moving polisher. This view has been held for some time by many workers;[17] it was not accepted in the first edition of this book, owing to the apparent difficulty of maintaining a sufficiently high temperature in the surface layers when considerable opportunities are present for conducting away the heat liberated by friction. But the recent work by Bowden and others[18] has shown, both theoretically and experimentally, that the *surface* temperature can, and does, rise quickly to the melting-point of the solid during sliding friction, and never rises higher than this.

In the process of compaction of sediments, when the great excess of water has been removed and the sedimentary particles are in contact with each other, skin-frictional heat is generated by reason of the particles sliding over one another. Any neokerogen present in the sediments will be subjected to this heat, causing its decomposition into gases and liquids, probably mainly the former. The liquids formed will be in solution in the gases by reason of pressure.[19] This skin-frictional heat will not result in any great rise in the temperature of the sediments in which the neokerogen is decomposed because the heat energy will be converted into chemical energy contained in the gases and liquids generated

[16] Neil K. Adam, *The Physics and Chemistry of Surfaces*, 2d ed., p. 173. Oxford Press (1938).

[17] *Cf.* discussion with Macaulay, *Nature*, Vol. 118 (1926), p. 339; Vol. 119 (1927), pp. 13, 162, 279.

[18] *Proc. Roy. Soc. A.*, Vol. 154 (1936), p. 640; Vol. 160 (1937), p. 575.

[19] Sage and Lacey, *Volumetric and Phase Behavior*, Stanford University Press.
Erik Schroer, *Zeits. Physik. Chem.*, 129 (1927), pp. 79–110.
Villard, *Jour. de Phys.* (3), 5 (1896), p. 453.
Nernst, *Theoretical Chemistry*, Macmillan and Company, New York.

by the decomposition of the neokerogen. A considerable amount of the gases thus formed will be unsaturated because they are formed by heat decomposition and, therefore, are extremely reactive. The composition of the gases and liquids formed from the decomposition of the neokerogen is dependent on: (1) composition of the neokerogen, (2) temperature, and (3) composition of the sediments containing the neokerogen.

The condition of the neokerogen when it is decomposed by the skin-frictional heat developed during compaction differs from that of the kerogen occurring in present-day oil shale only by the effect of the greater geologic time involved, which probably has resulted in the kerogen in oil shales being more stable than the neokerogen which was decomposed during compaction. The probable reason why the kerogen in oil shales was not destroyed during compaction is that there was not sufficient mineral matter present in proportion to the organic material, so that the neokerogen acted as a cushion during compaction thus reducing the amount of surface frictional heat. The ash content of oil shales varies from about 45 per cent to 80 per cent, the average being about 60 per cent.[20] The tests which have been made to produce petroleum from oil shales by pressure did not accomplish the desired result because pressure alone will not decompose kerogen. The decomposition of neokerogen in nature by compaction is due to the high skin temperature on the particles by reason of sliding friction and not because of pressure alone. The pressure is necessary to obtain compaction but, without the presence of sufficient mineral particles in contact to generate skin-frictional heat, the neokerogen is not decomposed and oil shales with the so-called kerogen result.

FILM MOVEMENT

There is a large amount of experimental evidence to support the statement that solids are permeable to matter.[21] This flow of matter through solids occurs not only along the surfaces between grain boundaries in the solid but also along the surface of crystal lattices.[22] The following extracts from Adam illustrate some of the factors which influence the mobility of matter through solids.

> There is no doubt, however, that *some* lateral motion of the molecules in films adsorbed with greater or less intensity on the surface of solids can, and frequently does, occur.
>
> If the liquid resting on a solid is volatile, it can distribute itself along the surface of the solid through the vapour.
>
> These experiments are sufficient to prove that lateral motion of molecules along the surface of a solid can, and often does, occur. But there is much further evidence, pointing particularly to a rather high degree of mobility along the surface, of atoms or molecules which have just hit the solid from the vapour phase.

[20] "Notes on the Oil Shale Industry," *U. S. Bur. Mines* (May, 1919), p. 3.

[21] Richard M. Barrer, *Diffusion in and through Solids*, The Macmillan Company, New York (1941).

[22] Neil K. Adam, *The Physics and Chemistry of Surfaces*, 2d ed., pp. 215, 217, 254. Oxford Press (1938).

It is thus evident that atoms or molecules in process of being deposited on a crystal are mobile. There is some reason to suppose that the surface molecules even of crystals or adsorbed layers, which have been formed for some time and may be considered stable, can also move along the surface.

It is also probable that the molecules are more or less mobile in the adsorbed layer, and can move along the surface. This motion may, however, as Lennard-Jones points out, be a series of "activated" hops from one place of low potential energy to another, not necessarily an adjacent one, rather than a continuous motion such as exists in the three dimensions of a gas. Although the mobility in "molecularly" adsorbed layers is much greater, as a rule, than in chemisorbed layers, there is no absolute distinction, for some chemisorbed layers, at any rate, become mobile to some extent on raising the temperature.

Based on the foregoing facts of film movement, the statement can safely be made that the gases and liquids formed as the result of the decomposition of neokerogen by the skin-frictional heat generated by the sedimentary particles sliding over each other will travel as films along the surfaces of the sedimentary particles and through the particles themselves along the crystal faces in the particles. This migration of these gases and liquids sets in motion the forces which cause the formation of an oil pool. In order to understand the mechanism of the formation of an oil pool, it is necessary to have some knowledge of the possible effect of capillarity and catalysts on these gases and liquids.

CAPILLARITY

Another phenomenon which is of importance to this subject is the condensation of gas to a liquid by adsorption to the walls of a capillary.[23] This condensation is due to the fact that a liquid having a convex surface has a vapor pressure greater than that of the same liquid with a plane surface, while the vapor pressure of a liquid having a concave surface is lower than that of the same liquid with a plane surface.[24] The reduction in vapor pressure by reason of the concavity in capillaries facilitates condensation. This accounts for the large volumes of gas that can be adsorbed by charcoal which contains capillary pores. Because of this condensing effect of capillaries, the rate of the weight movement of the decomposition products in fine-grain sediments is faster than in coarser materials. As indicated, the mobility of the molecules which have just hit a solid from the vapor phase is great, which also facilitates the rate of movement in the fine-grain sediments since the decomposition products from the neokerogen are mainly gaseous at the time of formation. When these films of condensed gases arrive at areas where the space between the sedimentary particles is greater, the increased vapor pressure occasioned by the increase in the diameter of the capillaries liberates gases. Thus, any zone having a high porosity in contact with fine-grain sediments along whose surfaces these film decomposition products of neokerogen are traveling will become filled with gases, which, as previously stated, are in a large

[23] *Ibid.*, p. 253.

[24] *Ibid.*, p. 15.

measure unsaturated; hence, reactive. It is these gases and the liquids dissolved in them from which petroleum is formed by the catalytic effect of the surfaces of the sedimentary particles. ***This porous zone can be in a syncline; hence, oil pools can be formed in synclines.***

CATALYTIC FORMATION OF PETROLEUM

Catalytic agents are substances which appear not to take part in a chemical reaction, as indicated by the fact that they apparently exist in their original condition at the completion of a reaction, but whose presence is required either to initiate or to accelerate the reaction. The subject is a very complex one and, as yet, the mechanism is not clearly understood. Certain facts, however, have been established which can be applied to the problem under consideration.

Catalysis is a surface phenomenon and is related to the heterogeneity of the catalytic agent.[25] The addition of some substances, termed promoters, to the catalyst increases the catalytic action.[26] This increased catalytic action has been attributed to an action at the linear boundary on the surface between the two or more catalysts.[27] The oxides of metals such as iron, aluminum, copper, tungsten, silicon, sodium, and many others, may be catalysts for various reactions. Starting with the same reacting compounds and varying the composition of the catalyst, different end products are obtained, as indicated by the following quotation from Adam.[28]

> For hydrogenation reactions, particularly the synthesis of methanol from carbon monoxide and hydrogen, oxide catalysts are of immense technical importance. Here the choice of catalyst makes large qualitative, as well as quantitative, differences.[29] While Sabatier found that nickel hydrogenates this gas to methane, Fischer[30] obtained a most complicated mixture of alcohols, ketones, and acids, using iron and alkalies as catalyst; and a suitable choice of oxides produces pure methanol. Zinc oxide is most frequently used, and it is generally promoted with chromium oxide. The addition of a little alkali to this oxide mixture promotes the production of higher alcohols. Ferric oxide is said to convert the mixture of carbon monoxide and hydrogen mainly into methane and liquid hydrocarbons; but if a little sulphur is added to the iron oxide, methanol is formed instead.

The application of these facts of surface chemistry renders understandable the formation of petroleum from the gases and liquids formed from neokerogen. The products of the skin-heat decomposition of neokerogen travel in all directions

[25] *Ibid.*, p. 233.
Twelfth Catalysis Report, National Research Council, 1940. John Wiley and Sons. New York.

[26] Neil K. Adam, *op. cit.*, p. 236.

[27] *Ibid.*, p. 241.

[28] *Ibid.*, p. 240.

[29] Mittasch, *Zeits. Electrochem.*, Vol. 36 (1930), p. 578.
Natta, *Giorn. Chem. Ind. Appl.*, Vol. 12 (1930), p. 13.
Morgan and Bone, *Proc. Roy. Soc. A.*, Vol. 127 (1930), pp. 244, 254.
Frolich *et al.*, *Indus. Eng. Chem.* (1929), p. 1052; (1930), p. 1051.
Huffman and Dodge, *ibid.* (1929), p. 1056.

[30] *Berichte*, Vol. 56 (1923), p. 2429, and elsewhere.

from the point of decomposition as films on the surfaces of the sedimentary particles and along crystal surfaces inside the particles. These products of the decomposition of neokerogen accumulate in traps, where they are subjected to the catalytic effect of the surfaces of the sediments with which they are in contact. While some catalytic transformation may occur during the movement of the decomposition products to the trap, the major transformation occurs in the trap largely because of the time factor. The hydrocarbons formed in the trap are dependent on the composition of the decomposition products entering the trap, the composition of the sediments in the trap, temperature, pressure, and time. These factors would also appear to govern whether the petroleum formed, if any, is asphaltic, paraffinic, or mixed base, and they also govern the amount and composition of the gas. Even in sands consisting mainly of silica, there is a large variety of minerals. This subject is thoroughly discussed by F. W. Clarke.[31] J. W. Retgers[32] found in sands of which 90 per cent to 95 per cent was quartz, garnet, augite, hornblende, tourmaline, epidote, staurolite, rutile, zircon, magnetite, ilmenite, orthoclase, calcite, apatite, and a number of subordinate minerals. The surfaces of contact between these different minerals act to produce an effect equivalent to the promoter effect when two or more compounds are used simultaneously as catalysts. When the fact is considered that changes in the catalyst present with the same reacting materials produce a variety of compounds, as previously illustrated, the widely varying composition of petroleum is understandable, especially when the differences in the composition of the gases and liquids formed from the neokerogen are considered, together with the complexity of the catalytic surfaces available in sediments.

The condition which favors the formation of petroleum is the slow decomposition of the neokerogen by heat of friction which results in the movement into the trap of the compounds formed. These compounds differ from the gases formed by bacterial action in that the evolution of gases by bacterial action is more rapid, and the gases are saturated. The whole problem of the migration of oil as such is eliminated by this theory because oil does not occur to any major extent outside of the trap. After petroleum is formed in the trap, it may move from its place of formation by reason of structural changes via crevices and fault and bedding planes. However, this movement can not be considered as a means of accumulating oil, but simply a movement of the position of the oil. In accordance with the principles just outlined it appears that *oil does not move into a trap; it forms in the trap*. This explanation of the origin and accumulation of petroleum satisfies conditions found in nature, and is in accord with well recognized physical chemistry principles. The inability of Trask[33] to find petroleum in recent sediments, and the comparatively small amount of petroleum found in shales and in

[31] F. W. Clarke, "The Data of Geochemistry," *U. S. Geol. Survey Bull.* 770, 5th ed., pp. 505–507.

[32] *Neues Jahrb.*, Vol. 1 (1896), p. 16; *Rec. Trav. Chim.*, Vol. 11 (1892), p. 169.

[33] Parker D. Trask, *Origin and Environment of Source Sediments of Petroleum*, Chap. VIII. Gulf Pub. Co., Houston, Texas (1932).

the sediments from the producing formation near oil pools are understandable by the application of these principles. The major transformation into petroleum of the products of the heat decomposition of neokerogen occurs in the trap. Such oil as is found outside of the trap in the same sediments is due to small local traps. The fact that in distilling oil shales ammonia is recovered indicates that some of the nitrogen in the original organic débris remains in the organic residue (kerogen), which is in accord with the fact that the protein in cabbages and cucumbers is only slightly attacked in the formation of sauerkraut and pickles, thus tending to support the validity of the comparison of the formation of neokerogen and kerogen with the formation of sauerkraut and pickles.

The following statement by Emmett[34] lends support to the idea that the surface of the sedimentary particles is an important factor in the conversion of the decomposition products of neokerogen into petroleum.

> Since the discovery of the phenomenon of catalysis it has been recognized that in selecting a catalyst the two principal factors to be considered are its chemical composition and the extent of its surface. The first of these has gradually come to include not only the chemical nature of the major component of the catalyst but also the nature of various added promoters or activators. Such guiding principles as have been deduced for choosing the proper catalyst material and promoter for a given reaction are treated fully in the chapters dealing with the application of catalysis to various types of reactions. It is the second factor, the physical state of subdivision, that will be discussed in the present chapter.
>
> It has long been the practice of those seeking to develop catalysts to increase the "surface area" of the catalytic material as much as possible, either by using more finely divided catalyst particles or by increasing the porosity of the catalyst, or by both. No common understanding has existed, however, about quantitative relations between particle size, porosity, catalyst surface area, and catalyst activity.

CONCLUSIONS

The forces of Nature are dynamic, not static. The factors which resulted in the formation of oil from organic débris in the past are still in operation. This means that oil is being formed now. Wherever organic matter is being deposited in sediments under saline conditions, neokerogen is formed and the gases from the skin-heat decomposition of this residue during compaction are being dissipated into space, unless they accumulate in traps where they are converted into oil. Since all sediments laid down contain some organic débris, there are two principal factors which govern the formation of petroleum: (1) a sufficient amount of organic débris, but not too much so as not to form oil shales, and (2) a trap in which the gases from the decomposition of the neokerogen can accumulate eventually to be converted into petroleum.

[34] *Twelfth Catalysis Report, National Research Council, 1940*, p. 53. John Wiley and Sons, New York.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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MIDDLE DEVONIAN SUBSURFACE FORMATIONS IN ILLINOIS[1]

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ABSTRACT

The underground extent in Illinois of Middle Devonian beds is outlined, and formation names are suggested for use in subsurface work. The Grand Tower limestone and Dutch Creek sandstone are together considered the equivalent of the Geneva dolomite. Limits of the sequence of Hamilton age in Illinois are defined, and the probable distribution of the included formations is indicated. The Alto formation is assigned a post-Hamilton age, in part equivalent to, but chiefly younger than, the Cedar Valley limestone in Illinois.

INTRODUCTION

The interest in deeper production in Illinois has made it advisable to review the Devonian stratigraphy of that region and establish in so far as possible detailed correlations of subsurface beds of that age within the basin area. The recently published studies[4] of L. E. Workman are a long step in that direction, and the present paper provides even more specific information. This work stems from field studies conducted intermittently since 1935, supplemented by subsurface examinations carried on in the laboratories of the Illinois Geological Survey. The writers are indebted to that organization for its coöperation in extending these facilities. The studies for this paper have been supported by the United States Geological Survey and the Smithsonian Institution.

DEVONIAN OUTCROP AREAS

Our stratigraphic determinations are based on study of essentially all the important Devonian outcrops surrounding the Illinois basin, followed by projection of these outcropping beds into the subsurface realm. The areas which have a direct bearing on the stratigraphy are five in number. In a clockwise direction around the basin they are: the upper Wabash Valley in Indiana, the Falls of the Ohio, southwestern Illinois (with adjacent exposures in Missouri), Calhoun County, Illinois (with adjacent Missouri outcrops), and the Davenport-Rock Island region. The correlation of beds occurring at these places is indicated in Figure 1.

SUBSURFACE CORRELATIONS

The maps accompanying this paper are intended to show present distribution, not paleogeography. Boundaries shown on these maps are of necessity approximate, and will be altered in detail by the addition of more well records. The general plan of distribution of these formations, however, will probably remain unchanged.

[1] Manuscript received, June 12, 1944. Published with the permission of the director of the United States Geological Survey, and the secretary of the Smithsonian Institution.

[2] Vassar College.

[3] United States National Museum.

[4] L. E. Workman, "Subsurface Geology of the Devonian System in Illinois," *Illinois State Geol. Survey Bull. 68A* (1944).

Age / Series	Stage	Rock Island, Ill. and Adjacent Iowa	Calhoun Co., Ill. and Adjacent Missouri	SW. Illinois and Adjacent Missouri	Indiana Upper Wabash Valley	Indiana Southern Part
Upper		Sweetland Ck. sh.	Bed of green sh.	Mountain Glen sh.	Delphi sh.	New Albany sh.
Middle Devonian	Taghanic	Cedar Valley ls. 90' Wapsipinicon ls. (A) 115'	Cedar Valley ls. in Ill. or Mineola, Cooper and Callaway ls. in Mo. 0-100'	Alto fm. 80'		
	Tioughnioga			Hamilton age: Lingle ls. 15'	Logansport ls. 15'	Sellersburg ls.: Beechwood 10'
	Cazenovia	Wapsipinicon ls. (C) 115'		Hamilton age: St. Laurent ls. 200'		Sellersburg ls.: Swanville 5' Silver Creek 24' Deputy 6' Speeds 13'
Middle or Lower Devonian	Onesquethaw	Wapsipinicon ls. (B) 115'		Grand Tower ls. 35' Dutch Creek ss. 30' Clear Creek chert 200'		Jeffersonville ls. 30' Geneva dol. 30'
Underlying Bed		Silurian	Silurian	Dev. Backbone ls.	Silurian	Silurian

FIG. 1.—Correlation of Middle Devonian outcrops of Illinois Basin area. Three possible positions for Wapsipinicon limestone are lettered in order of preference. Thickness in feet.

FIG. 1.—Correlation of Middle Devonian outcrops of Illinois Basin area. Three possible positions for Wapsipinicon limestone are lettered in order of preference. Thickness in feet.

GRAND TOWER, DUTCH CREEK, AND GENEVA FORMATIONS

At the type locality in Jackson County, the Grand Tower is a white to light brown, coarsely crystalline limestone, with partings and lenses of coarse rounded sand grains. The sand increases in amount toward the base, and no definite line can be drawn to mark the contact with the underlying Dutch Creek sandstone. In wells the main sand beds sometimes occur well up within the limestone. As they contain many fossil species in common, the Grand Tower and Dutch Creek seem to represent a single depositional and faunal unit.

South of Jonesboro, Union County, only the sandy Dutch Creek phase is present. The coarse crystalline sandy limestone can be recognized in most wells south of a line drawn from northern Jackson to Lawrence County. In this area the combined Grand Tower-Dutch Creek thickness varies from 15 to 55 feet. North of this line the crystalline limestone is replaced by fine-grained gray dolomite, containing the same type of sand found in the Grand Tower. This sandy dolomite contains the principal Devonian "pay" of the Illinois basin pools. In a few borderline wells the crystalline limestone and dolomite are both present in a section of normal total thickness, the dolomite commonly appearing below the limestone. As the dolomite occupies the same stratigraphic position, contains the same sand, and has the same thickness as the Grand Tower-Dutch Creek unit, it is assumed to be of like age. Lithologically it is distinct enough to deserve a separate formation name. This dolomite may be traced in wells into Indiana where it is correlative with the Geneva dolomite, and it is proposed to use that name in the Illinois subsurface for the dolomitic phase. The Geneva dolomite is equivalent to part of the Detroit River dolomite in the Michigan basin.

The sand and dolomite of the Geneva extend northward to the southern margin of the area from which the Devonian has been stripped. The thickness in the northeast part of the Geneva belt in Illinois ordinarily varies between 30 and 60 feet, but in Clark and Coles counties about 150 feet are present.

Fossils collected by the writers indicate that the Grand Tower-Dutch Creek sequence is Onondaga (Onesquethaw) in age. They may be, however, older than the Jeffersonville limestone of Indiana, which was not recognized in Illinois wells. The Jeffersonville is probably absent from Illinois, unless some beds above the Grand Tower limestone at the Bakeoven in Jackson County are proved to be of that age.

It has been suggested that the Grand Tower-Dutch Creek sequence may be equivalent to some part of the Wapsipinicon limestone of Iowa. No fossils support such a correlation, and as the two formations nowhere come in contact their depositional relations can not be observed. The three possible positions of the Wapsipinicon are indicated in Figure 1 by the letters A, B, C, the alphabetical order indicating the writers' conception of their probability.

LIMESTONE OF HAMILTON AGE

All of the New York state Hamilton formations are not present in Illinois, the Moscow and the upper part of the Ludlowville being absent, so that the term

FIG. 2

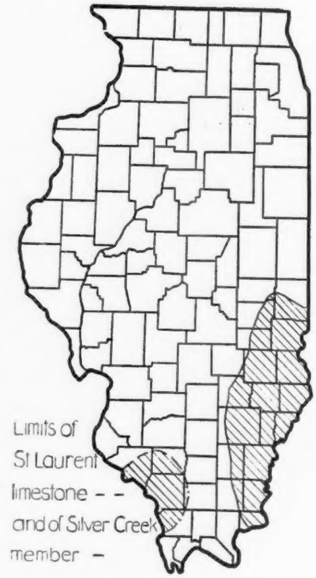

FIG. 3

FIG. 4

FIG. 5

as used here covers only part of Hamilton time. The formation and member names applied to outcrops in this area are indicated in Figure 1.

In well cuttings it is difficult to recognize formational subdivisions of the Hamilton. As no single formation name covers the entire range of time represented by these sediments in the basin, the writers propose that they be referred to simply as limestones of Hamilton age.

The lower boundary of the Hamilton equivalent in Illinois has been placed at various points, but is here restored to the level assigned it by Worthen[5] in 1868, at the contact between the sandy limestone of the Grand Tower-Dutch Creek sequence and the overlying more argillaceous limestone. This contact is well exposed on the west face of the Bakeoven at Grand Tower, Jackson County. The first 30 feet of argillaceous limestone above the Grand Tower here contain an equivocal fauna, but higher beds are unquestionably of Hamilton age.

In Jackson and Union counties a Hamilton age was formerly assigned to the St. Laurent, Misenheimer, Lingle, and Alto formations. In this paper the term Misenheimer is not used, the writers agreeing with J. M. Weller that the Misenheimer is only a highly leached phase of the Hamilton beds. The type Misenheimer is probably equivalent to part of the St. Laurent limestone.

The term "Lingle" is used to include only those limestones present at the type locality in southern Union County, with their correlatives. It rests on the St. Laurent limestone, and is overlain by the Alto formation, which is considered to be younger than Hamilton. The Lingle seems to be the most widely distributed portion of the Hamilton in Illinois, being present where any beds of that age are found. Toward the east the Lingle becomes the Beechwood limestone member of the Sellersburg of southern Indiana, and toward the northeast the Logansport limestone is its equivalent. In well cuttings the Lingle appears as brown, granular to crystalline limestone, ordinarily somewhat cherty, and containing crinoid, coral, and brachiopod remains in abundance. Argillaceous partings are present in minor amount, and oölitic beds may be found at the top. The probable thickness of the Lingle limestone is indicated in some well logs at the end of the paper. In those wells where the thickness appears abnormally high it is possible that the well has penetrated a coral-reef knob.

In southwestern Illinois the Lingle is underlain by brown limestone which is generally more argillaceous and less coralline. This is the equivalent of the St. Laurent limestone of Missouri. It is probable that the St. Laurent extends only into Union, Jackson, and parts of the adjoining counties, and that its disappearance accounts for the rapid thinning of the Devonian limestone away from that region.

In southeastern Illinois, from Hardin County north to Clark County, beds of Hamilton age thicken by the appearance of strata beneath the Lingle horizon. This lower material is predominantly light gray, fine-grained argillaceous limestone of marly character, containing chert nodules here and there, some dolomite

[5] A. H. Worthen, "Geology of Jackson County," *Geol. Survey Illinois*, Vol. 3 (1868), p. 63.

rhombs, and a few fossils. This marly rock continues into Indiana, and in the Falls of the Ohio region crops out as the lower part of the Sellersburg limestone, principally the Silver Creek member. The approximate limits of the Silver Creek lithologic type are shown in Figure 3.

CEDAR VALLEY LIMESTONE

The Cedar Valley limestone in well cuttings is separable from the Hamilton limestones only with some difficulty. The best criteria seem to be color and lithologic character. The purer limestone beds are light brown in color, while the argillaceous layers tend to be light buff or light bluish gray. The pure limestone is not commonly crystalline. The argillaceous beds are essentially lithified and fossiliferous marl, containing chert nodules here and there.

Fossils are common, but in routine examination of cuttings few diagnostic forms are likely to be observed. *Tentaculites*, which occurs throughout the Devonian limestones, is notably plentiful in the marly beds, where its shell is commonly pyritized. The ostracode genus *Kirkbyella*, rare in the Hamilton here, is the most common ostracode of the Cedar Valley beds. Trochiliscids are locally abundant in the marl.

In Marion and Fayette counties the Cedar Valley limestone contains one to five oölitic beds. These may represent a south-shore phase of some part of the formation.

Exact identification of members within the Cedar Valley limestone in wells is difficult. The main marly beds probably represent the *Atrypa bellula* zone of the Rapid limestone member. Some of the Solon member of the Cedar Valley is present beneath the marl in Illinois, and the higher limestones may be upper Rapid in age. The Coralville member of the Cedar Valley is probably absent. The distribution of the formation as a whole in indicated in Figure 4.

HOING SAND

In the two ranges of counties which comprise the westernmost bulge of Illinois sandstone beds occur at or near the base of the Devonian section. This sand, productive in the Plymouth-Colmar area, has been termed the Hoing sand. In the adjacent outcrop area in Missouri this sand may be studied at the surface. Examination of well and outcrop occurrences clearly shows that the sand is not a single definite bed, but a series of small lenses, each having little lateral extent. The sand is of local derivation, and represents the reworked material deposited by the advancing Cedar Valley sea. Sand of this type is probably confined to the area where it is already known to occur.

ALTO FORMATION

The Alto formation, at its type locality in northern Union County, contains at its top about 11 feet of hard brown, irregularly bedded, finely granular, dolomitic sandy limestone, with much brown chert. Beneath this lies about 70

feet of dark brown to dark gray, irregularly laminated silty to sandy shale, with a few one-foot layers of sandstone and sandy limestone. Some of these shales are dark enough to be confused with the Mountain Glen black shale above, if it were not for the intervening cherty limestone.

The Alto formation has been variously correlated with rocks of Hamilton and later age, but is here considered as entirely post-Hamilton in age.

In Macoupin, Montgomery, Bond, Marion, Fayette, and Shelby counties these dark shales and cherty limestones overlie and interfinger with the Cedar Valley limestone. The exact extent of the interfingering can not safely be determined from well cuttings, but its existence has been demonstrated in cores. The Alto formation is therefore regarded as partly equivalent to, and partly younger than, that part of the Cedar Valley limestone which occurs in south-central Illinois.

ILLUSTRATIVE WELL LOGS

To illustrate specifically some determinations of the Devonian formations discussed, brief logs of the Middle Devonian sections encountered in wells in 14 counties are appended.

	Depth in Feet
BOND COUNTY: HUBER'S KUNZ NO. 1, SEC. 11, T. 6 N., R. 5 W.	
Black shale	
Alto formation, 24 feet	1,790–1,814
Dark gray shale, gray dolomitic limestone, fine-grained dolomite with poorly rounded sand grains	
Cedar Valley limestone, 20 feet	–1,834
Brown, fine-grained to granular limestone or dolomitic limestone, with white chert, particularly in upper part	
Geneva and Dutch Creek, 57 feet	–1,891
Buff to white, fine-grained dolomite, somewhat porous, with beds of sandstone	
Clear Creek chert	
CHAMPAIGN COUNTY: SIDNEY'S WANDLING NO. 1, SEC. 10, T. 17 N., R. 10 E.	
Black shale	
Logansport limestone of Hamilton age, 92 feet	685–777
White, coarsely crystalline, fossiliferous limestone; some sand grains	
Geneva dolomite, 57 feet	–835
Light gray, fine-grained, porous dolomite	
Brown dolomite (Silurian)	
CLARK COUNTY: SNAVELY'S SCHOFFIELD NO. 1, SEC. 6, T. 11 N., R 11. W.	
Black shale	
Limestone of Hamilton age, 68 feet	2,215–2,283
Lingle? limestone, 23 feet. Light brown to white, coarsely crystalline fossiliferous limestone	
Sellersburg limestone (Silver Creek? member), 45 feet. White, marly limestone to dolomite, and white, coarsely crystalline limestone. Much white chert	
Geneva and Dutch Creek, 152 feet	–2,435
Light brown, medium crystalline dolomite, with scattered sand	
COLES COUNTY: FINESS *et al.*, TEMPLE NO. 1, SEC. 36, T. 14 N., R. 10 E.	
Black shale	
Alto formation? 30 feet	915–945
Brown, porous, crystalline dolomite, with some pyritic chert and brown sandstone	
Limestone of Hamilton age, 20 feet	–965
White to light brown, coarsely crystalline coral limestone; sand and chert rare	
Geneva and Dutch Creek, 145 feet	–1,110

Light gray fine-grained porous dolomite, with sand varying in amount up to half the sample

Dolomite (Silurian) 1,110–

FAYETTE COUNTY: B. & T'S. VAN ZANDT NO. 1, SEC. 24, T. 6 N., R. 1 W.

Black shale

Alto formation, 10 feet 2,820–2,830

Light brown limestone, light gray shale and gray, poorly sorted argillaceous sandstone

Cedar Valley limestone, 64 feet –2,894

Light buff, fossiliferous limestone, oölitic in middle, marly in lower part

Geneva and Dutch Creek, 65 feet –2,959

Light brown, finely crystalline vesicular sandy dolomite

Silurian

FORD COUNTY: ROTH'S HELMICK NO. 1, SEC. 36, T. 23 N., R. 7 E.

Logansport limestone, 20 feet 219–239

Brown to light gray, dolomitic, argillaceous fossiliferous limestone

Silurian? –437

Gray, argillaceous, vesicular dolomite

HENRY COUNTY: M. SMITH'S KEWANEE CITY NO. 3

Pennsylvanian shale

Cedar Valley limestone, 45 feet 365–410

Light brown, dolomitic limestone overlying light gray, argillaceous limestone and calcareous shale.

Wapsipinicon limestone, 40 feet –450

Light gray to buff lithographic limestone

Silurian dolomite 450–

JEFFERSON COUNTY: SHELL'S RAGAN NO. 1, SEC. 25, T. 2 S., R. 1 E.

Black shale

Alto formation, 32 feet 3,730–3,762

Brown, fine-grained impure pyritic limestone, with some chert and dolomite, and layers of sandstone and brown shale

Limestone of Hamilton age, 18 feet –3,780

Lingle limestone; brown, granular limestone and dark gray shale, both fossiliferous

Grand Tower and Dutch Creek, 17 feet –3,797

Light buff to white, coarsely crystalline limestone with layers of calcareous sandstone

Dolomitic limestone (Silurian?) 3,797–

JOHNSON COUNTY: TUNNEL HILL'S BONNER NO. 1, SEC. 30, T. 11 S., R. 3 E.

Black shale

Alto formation, 39 feet 3,993–4,032

Brown, fine-grained pyritic and cherty dolomitic limestone; gray shale

Limestone of Hamilton age, 33 feet –4,065

White and light brown, coarsely crystalline cherty dolomitic limestone, with white shale partings

Grand Tower and Dutch Creek, 51 feet –4,116

40 feet of white, coarsely crystalline limestone resting on 5 feet of gray dolomite (Geneva lithology) and 6 feet of sandstone

Dolomites (Silurian?) 4,116–

LAWRENCE COUNTY: BELL'S WAMPLER NO. 1, SEC. 27, T. 5 N., R. 11 W.

Black shale

Limestone of Hamilton age, 170 feet 3,045–3,215

Logansport? limestone, 105 feet. Brown, slightly cherty, very fossiliferous limestone with black and gray shale beds; probably a bioherm. Sellersburg limestone (Silver Creek? member), 65 feet. Gray, argillaceous, fossiliferous limestone without chert

Grand Tower and Dutch Creek, 35 feet –3,250

White to light brown, coarsely crystalline limestone with a few sand grains

Unidentified formation, 12 feet (to total depth) –3,262

White, argillaceous, fine-grained dolomitic limestone, perhaps of Geneva age

MONTGOMERY COUNTY: TOPF *et al.* BREITENBACH NO. 1, SEC. 13, T. 9 N., R. 4 W.

Black shale	
Alto formation, 19 feet	2,070–2,089
Gray, unfossiliferous dolomite, black shale and fine-grained gray sandstone	
Cedar Valley limestone, 33 feet	–2,122
Buff to light gray, argillaceous to marly limestone, somewhat fossiliferous. 2,113–2,122 feet may be Hamilton in age	
Geneva and Dutch Creek, 28 feet	–2,150
Light buff, finely crystalline dolomite, gray, argillaceous fossiliferous limestone, both containing sand; 8 feet of white crystalline sandstone at base	

SHELBY COUNTY: SEABOARD'S P. MILLER NO. 1, SEC. 32, T. 11 N., R. 2 E.

Black shale	
Cedar Valley and Alto formation, 35 feet	2,925–2,960
Brown shale and gray sandstone interbedded with greenish, coarsely crystalline coral limestone	
Limestone of Hamilton age, 50 feet	–3,010
White, porous, crystalline coral limestone with a few sand grains and dolomite rhombs	
Geneva and Dutch Creek, 45 feet	–3,055
Light gray, fine-grained dolomite with some porosity, and some beds of dolomitic sandstone	

VERMILION COUNTY: MYER'S FOREMAN NO. 1, SEC. 13, T. 18 N., R. 14 W.

Black shale, with 2 feet loose sand at base	
Alto (or Squaw Bay?) limestone, 18 feet	1,376–1,394
Brown, medium granular dolomitic limestone	
Logansport limestone, 21 feet	–1,415
White, crystalline to marly, fossiliferous limestone	
Geneva and Dutch Creek, 37 feet	–1,452
Light gray to buff, granular dolomite, sandy toward base	
Silurian dolomites	

WHITE COUNTY: KINGWOOD'S MARTIN NO. 1, SEC. 13, T. 7 S., R. 8 E.

Black shale	
Alto? formation 25–40 feet	4,910–4,935
Black and brown limestone, gray shale and brown and gray chert	
No samples, 15 feet	–4,950
Limestone of Hamilton age, 210 feet	–5,160
Lingle? limestone, 140 feet. Brown, granular crinoid-coral limestone with gray and white shale and marl beds; light gray chert scattered throughout. Sellersburg limestone (Silver Creek? member), 70 feet. Light brown to buff fossiliferous limestone with marly streaks; chert common	
Grand Tower and Dutch Creek, 35 feet	–5,195
Light buff to light brown, medium to coarsely crystalline limestone with some scattered sand and rare chert	
Grand Tower and Dutch Creek? 25 feet	–5,220
Buff, medium crystalline dolomitic limestone with little sand and common chert. Some white sandy marl present. May be upper part of Clear Creek chert	

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GEOLOGICAL NOTES

CORRELATION OF SUBSURFACE DEVONIAN OF SANDOVAL POOL, MARION COUNTY, ILLINOIS, WITH DEVONIAN OUTCROP OF SOUTHWESTERN ILLINOIS[1]

W. FARRIN HOOVER[2]
Lake Charles, Louisiana

In the stratigraphic column of the Sandoval pool, T. 2 N., R. 1 E., Marion County, Illinois (Fig. 1, column 2), the limestone immediately above the black shale is designated the Rockford limestone, and the underlying black shale the New Albany black shale. Both of these formations are thought to be Mississippian in age. The argillaceous greenish siltstone with rounded and frosted sand grains found at the base of the black shale and above the underlying limestone is considered to represent the basal phase of deposition of Mississippian clastics. This sandstone which immediately overlies the Devonian limestone has been correlated with the Hardin sand of Kentucky and Tennessee on the suggestion of J. Rex McGehee[3] of the Shell Oil Company, Inc. The Hardin sandstone or siltstone is a basal clastic of the Mississippian, and indicates an unconformity between the Mississippian and Devonian systems. Further evidence of this Mississippian-Devonian unconformity is afforded by the differences in structural trends indicated in comparing a contour map drawn on the top of the Devonian limestone with one contoured on the base of the Meisenheimer. It is this unconformity that is responsible for the variance in the interval between the top of the Devonian limestone and the pay section in the Sandoval, Centralia, and Bartelso pools, the amount of which is mentioned later. Weller[4] suggests the presence of an unconformity between the Alto limestone and the Mountain Glen formations in the Darty Creek section in Union County, Illinois. This is the same unconformity as the one between the New Albany black shale and the top of the Devonian limestone in Marion County, Illinois.

That part of the Devonian limestone so far penetrated at Sandoval has been divided into five formations, namely Alto, Lingle, Meisenheimer, Grand Tower, and Dutch Creek. The upper 10 feet or less of the Devonian in the Sandoval section has been tentatively correlated with the Alto of the Darty Creek section, although there is a strong possibility that the Alto, or its equivalent, is not present in the central part of the Illinois basin. The lower 15 feet of the upper 25 feet of the Devonian in the Sandoval area may be definitely classified as Lingle on the

[1] Paper originally read before the Society of Economic Paleontologists and Mineralogists at Chicago, April, 1940. Manuscript received, May 18, 1944.

[2] Geologist, Stanolind Oil and Gas Company.

[3] J. Rex McGehee, personal communication.

[4] Marvin Weller, "Devonian System," *Guide Book Thirteenth Field Conference Kansas Geological Society* (1939), pp. 127–30.

basis of lithologic character and faunal assemblage. The latter indicates that these beds are Hamilton in age. The oölite bed found on the outcrop along Darty Creek in Union County, Illinois, is present in the Sandoval field. These oölites are characteristically small, brown and white-banded, with very thick growth rings.

Below the beds of Lingle age are 10–12 feet of sandy glauconitic limestone grading into sandstone which contains large amounts of glauconite. Fossils from cores in the wells at Sandoval have been identified by V. D. Winkler[5] as Hamilton and Marcellus in age. This indicates that the Meisenheimer of the Sandoval area is the Marcellus part of the Lingle. Carey Croneis,[6] of the University of Chicago, has assigned the Beauvais of Missouri to the Marcellus part of the Hamilton; thus, it seems that the Meisenheimer of the Sandoval pool, the Meisenheimer of the outcrop area in southwestern Illinois, and the Beauvais of Missouri are all equivalent and were deposited at about the same time. The lithologic differences therefore represent a difference in facies of sedimentation. The Beauvais of Missouri is sandstone somewhat similar to the St. Peter; the Meisenheimer of the outcrop is silty to sandy shale; and the Meisenheimer in the Sandoval area calcareous sandstone to very sandy limestone.

The glauconite in the Meisenheimer of the Sandoval area suggests the presence of an unconformity between the Meisenheimer and the underlying Grand Tower. On the outcrop, the contact between the Meisenheimer and Grand Tower is not visible in the section along Darty Creek or in the Devils Bake Oven. In Cokins and Manta's Coe No. 1, NE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 13, T. 1 N., R. 1 W., Clinton County, Illinois, the Meisenheimer-Grand Tower contact was cored. This contact is an unconformable one as there is a distinct unconformity between the Meisenheimer and Grand Tower shown in this core (Fig. 2). The Meisenheimer has isolated rounded pebbles of Grand Tower embedded in a matrix of typical calcareous glauconitic sandstone of Meisenheimer age. This Grand Tower-Meisenheimer unconformity separates the Marcellus or basal Hamilton (upper Middle Devonian), Alto, Lingle, and Meisenheimer section from the Onondaga or lower Middle Devonian formations (Grand Tower and Dutch Creek). Additional proof of the Meisenheimer (Hamilton)-Grand Tower (Onondaga) unconformity is found in the fact that the interval between the top of the "White Crystalline" limestone (Grand Tower) and the top of the "pay" is zero in the Bartelso pool, 12–18 feet in Centralia, and a constant interval of 20 feet in the Sandoval pool. The relatively constant interval at Sandoval suggests that the erosion surface developed on the top of the Grand Tower before the tectonic movements forming the Sandoval structure occurred. The difference in thickness between the Grand Tower at Sandoval and the Grand Tower on the outcrop in Jackson County suggests that only the basal part of the Grand Tower is present at Sandoval. The presence of glauconite in the overlying Meisenheimer sandy

[5] V. D. Winkler, Geological Laboratory, Standard Oil Company of Venezuela, Caripito, Venezuela, S. A., personal communication.

[6] Carey Croneis, unpublished manuscript.

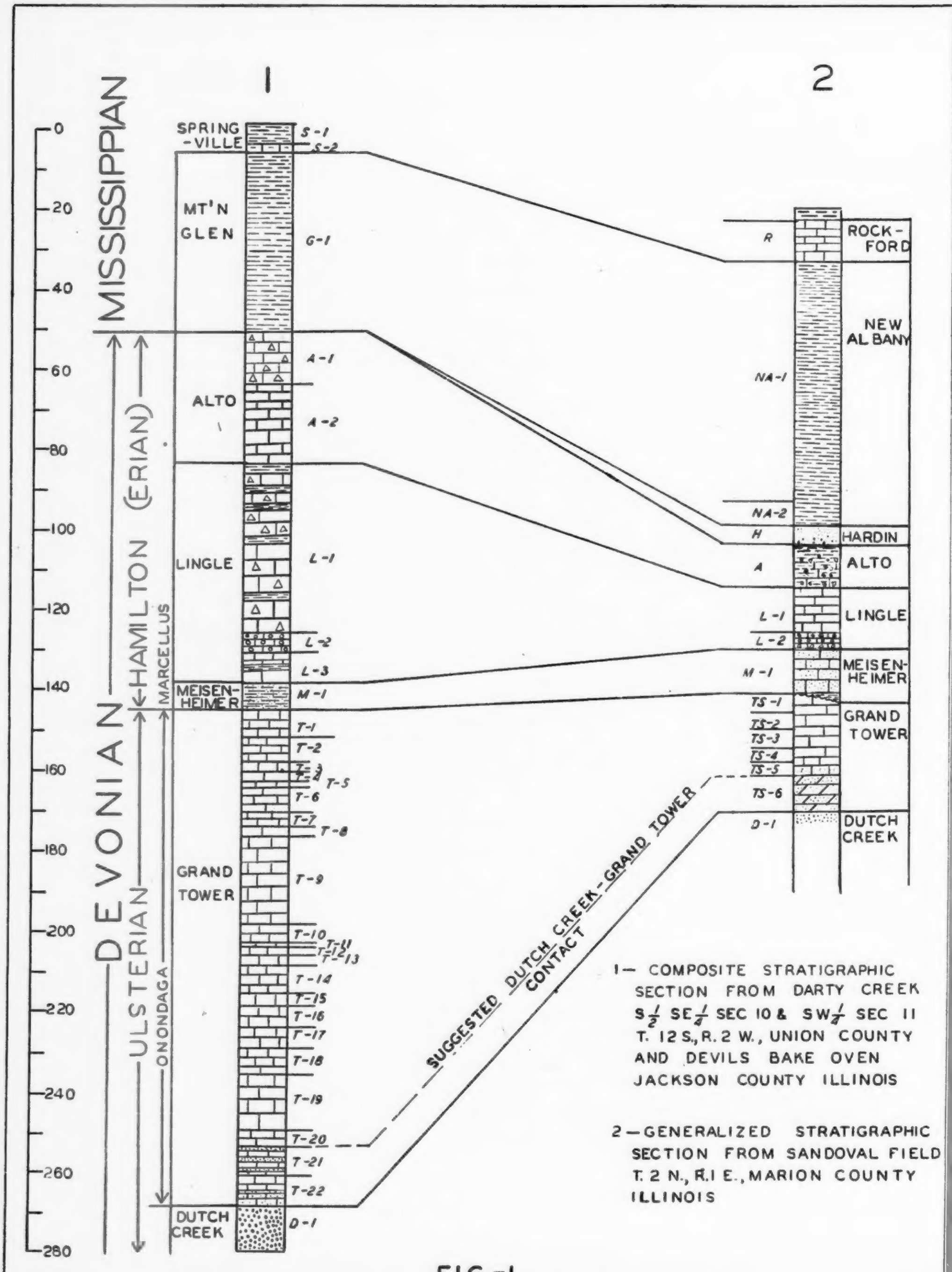
1
2
MISSISSIPPIAN
DEVONIAN
HAMILTON (ERIAN)
ULSTERIAN
MARCELLUS
ONONDAGA
SPRING-VILLE
MT'N GLEN
ALTO
LINGLE
MEISEN-HEIMER
GRAND TOWER
DUTCH CREEK
ROCK-FORD
NEW ALBANY
HARDIN
ALTO
LINGLE
MEISEN-HEIMER
GRAND TOWER
DUTCH CREEK
SUGGESTED DUTCH CREEK-GRAND TOWER CONTACT
1— COMPOSITE STRATIGRAPHIC SECTION FROM DARTY CREEK S 1/2 SE 1/4 SEC 10 & SW 1/4 SEC 11 T. 12 S., R. 2 W., UNION COUNTY AND DEVILS BAKE OVEN JACKSON COUNTY ILLINOIS
2—GENERALIZED STRATIGRAPHIC SECTION FROM SANDOVAL FIELD T. 2 N., R. 1 E., MARION COUNTY ILLINOIS

FIG-1

LITHOLOGIC DESCRIPTIONS
(To accompany Figure 1)

COLUMN 1. COMPOSITE SECTION FROM SOUTHWESTERN ILLINOIS						COLUMN 2. STRATGRAPHIC COLUMN OF SANDOVAL POOL, MARION CO., ILLINOIS		
Sys.	Series	Group	Formation	Unit No.	Description	Formation	Unit No.	Description
MISSISSIPPIAN			SPRINGVILLE SHALE	S-1	Shale, green silty	ROCKFORD	R	Limestone, buff-tan, dense; commonly lithographic to very fine-grained
				S-2	Limestone, argillaceous, very impure with distinctly mottled appearance			
			MOUNTAIN GLEN	G	Shale, black, hard with *Sporangites* near base	NEW ALBANY	NA-1	Shale, black to dark brown, bearing *Sporangites*
							NA-2	Shale, black to dark brown with sporangites. Faintly granular, commonly thinly laminated with limestone nodules ¼ inch in diameter. Vein calcite present in some fragments
						HARDIN	H	Siltstone, greenish, with streaks of silty greenish shale in upper part. Siltstone, green, fine-grained with pyrite, coarse sand grains and phosphatic nodules. Sand grains rounded and frosted
DEVONIAN	HAMILTON (ERIAN)		ALTO	A-1	Limestone, hard, dense with black chert nodules	ALTO	A	Shale, brown to black, grading to brownish black limestone, very marl-like in appearance, containing small crinoid fragments
				A-2	Limestone, gray, hard, cherty; thin-bedded in upper part, becoming thick-bedded near base			
			LINGLE	L-1	Limestone, hard, dark, impure in part, shaly with dark brown shale	LINGLE	L-1	Limestone, dark to medium gray in upper part, becoming gray to tan in lower part, crystalline with fossiliferous streaks. Some fossils finely fragmented cemented in calcite matrix
				L-2	Limestone, pinkish tan, containing thick-ringed siliceous oölites		L-2	Limestone, tan, oölitic, with small thick-ringed siliceous oölites
				L-3	Covered interval. Interpreted thus, to account for difference between measured section and thickness given to Lingle in published reports			
		MARCELLUS	MEISENHEIMER	M-1	Shale, drab, silty to sandy	MEISENHEIMER	M-1	Limestone, dark gray, argillaceous to arenaceous, with blue-green rods or spots of glauconite
								—*Unconformity*— Brown dolomitic shale with showings of free oil (apparently in pockets on top of underlying limestone)
	ULSTERIAN	ONONDAGA	GRAND TOWER	T-1	Limestone, massive, hard, gray, subcrystalline			
				T-2	Limestone, dark gray, hard, with *Chonetes* zone			
				T-3	Limestone, gray, hard			
				T-4	Limestone, argillaceous, dark gray			
				T-5	Limestone, dark gray with fossil concentrates of *Chonetes*			
				T-6	Limestone, shaly, gray, in beds 2–8 inches in thickness			
				T-7	Limestone, dark gray, shaly, beds 6–11 inches in thickness			
				T-8	Limestone, dark gray, impure, thin-bedded. Stropheodonta zone			
				T-9	Limestone, gray to brown, imperfectly bedded. Fossils abundant in well defined zones or streaks			

LITHOLOGIC DESCRIPTIONS—(*Continued*)
(To accompany Figure 1)

COLUMN 1. COMPOSITE SECTION FROM SOUTHWESTERN ILLINOIS						COLUMN 2. STRATIGRAPHIC COLUMN OF SANDOVAL POOL, MARION CO., ILLINOIS		
Sys.	Series	Group	Formation	Unit No.	Description	Formation	Unit No.	Description
DEVONIAN	ULSTERIAN	ONONDAGA		T-10	Limestone, dark gray, drab in color, with thin chert beds			
				T-11	Limestone, dark gray, impure			
				T-12	Limestone, gray, impure, thin-bedded			
				T-13	Limestone, dark, impure, imperfectly bedded			
				T-14	Limestone, dark gray, fine-grained, imperfectly bedded			
				T-15	Limestone, light gray, subcrystalline, massive			
				T-16	Limestone, light gray, subcrystalline, thin- to medium-bedded			
				T-17	Limestone, gray, subcrystalline, fossil breccia at base	GRAND TOWER	TS-1	Limestone, gray to white with colonial coral *Prismatophyllum*
				T-18	Limestone, gray, crystalline to subcrystalline. Thin-bedded, fossiliferous. Fossils imperfectly preserved		TS-2	Limestone, dolomitic, brown, dense to finely crystalline, fossiliferous (crinoids and brachiopods dominant). Dolomite crystals with traces dead oil
				T-19	Limestone, gray, crystalline, thick-bedded with abundant trilobite remains		TS-3	Limestone, white, fine-grained, fossiliferous. Many crinoid fragments
				T-20	Limestone, gray, crystalline to subcrystalline. Fossils abundant in lower part, iron-stained at top		TS-4	Limestone, light gray, coarse crystalline, very fossiliferous
				T-21	Limestone, gray, crystalline with interbedded sandstone, coarse, calcareous		TS-5	Limestone, blue-gray, dense to finely crystalline grading to sandy fine-grained dolomitic limestone in thin beds 4–15 inches thick
				T-22	Limestone, coarse-grained and coarsely crystalline, gray, in beds 6–18 inches thick, arenaceous in basal part		TS-6	Dolomite, brown, sandy; fossiliferous (brachiopods, bryozoans, and corals dominant). Very spongy, vesicular porosity. Saturated
			DUTCH CREEK	D-1	Sandstone, white, medium- to coarse-grained, porous; locally with fossil casts and molds forming vesicular type of porosity. Fossils principally horn coral. Individual sand grains rounded and frosted	DUTCH CREEK	D-1	Sandstone, medium-grained, cemented with silica cement, almost quartzitic in hardness. Slightly stained with oil

limestone supports the interpretation that the unconformity cored in the Centralia pool is also present at Sandoval.

In the Sandoval pool the formation immediately below the Meisenheimer is approximately 20 feet thick. It is white, crystalline, coralline limestone in which a colonial coral, probably *Prismatophyllum*, is present. This bed grades vertically into sandy dolomite with a scoriaceous texture; hence, it is porous. The voids are commonly lined with quartz crystals. In the Big Four Oil and Gas Company's Chaffin No. 1, Sandoval pool, this pay section grades vertically downward into a sandy zone that is so highly cemented by silica that it is quartzitic in character. This zone is suggestive of the Grand Tower section described by Savage[7] from the Devils Bake Oven in Jackson County, Illinois. In the Centralia pool, the zone below and including the "pay" consists of a series of interbedded cherty lime-

[7] T. E. Savage, "The Grand Tower Formation of Illinois and Its Relation to the Jeffersonville Beds of Indiana," *Trans. Illinois Acad. Sci.*, Vol. 5, No. 3 (1910).

stones and sandstones. The lithologic character and stratigraphic correlations suggest that the Dutch Creek of the outcrop in southwestern Illinois may in reality be the basal sandy phase of the Grand Tower limestone, which, where

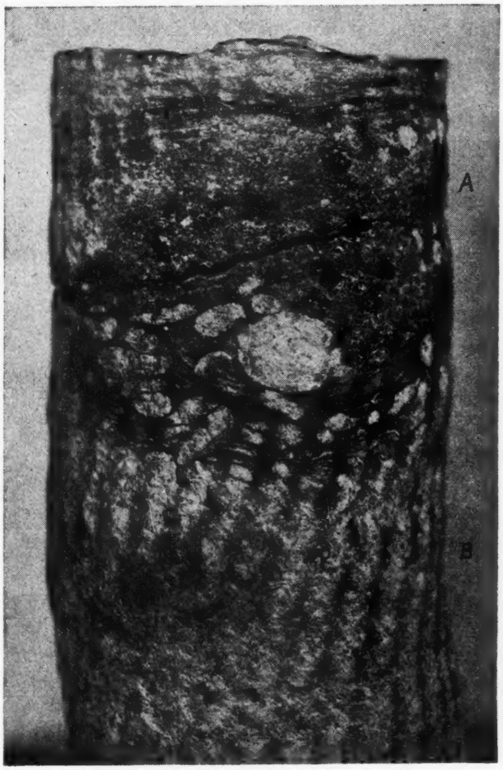

FIG. 2.—Core from Cokins and Manta's Coe No. 1, NE. ¼, SW. ¼, SE. ¼, Sec. 13, T. 1 N., R. 1 W., Clinton County, Illinois. Upper part (A) is Meisenheimer; lower (B) is Grand Tower. Note pebbles of Grand Tower limestone embedded in matrix of sand and sandy limestone of Meisenheimer. Specimen photographed through courtesy of Adams Felmont Corporation.

well developed, as a basal sandstone of the Ulsterian series, has been separated from the Grand Tower as the distinct Dutch Creek formation.

It is therefore suggested that the basal sandy zone in the Sandoval and Centralia pools, and the Dutch Creek formation of the Darty Creek section, Union County, Illinois, represent a sandy zone or basal sandstone at the base of the Ulsterian series of the upper Lower Devonian. Such a stratigraphic position, on basis of analogy, suggests a correlation of these sandy zones with the Schoharie at Schoharie, New York.

ELEVATIONS WITH PLANE TABLE AND SPEEDOMETER[1]

T. DEAN MUNDORF[2]
Indianapolis, Indiana

Many expedients have been employed by geologists in using a plane table without the assistance of a rodman, but little has been published about the more unorthodox methods. At present when man power is becoming more and more scarce, these shortcuts become correspondingly more important. For this reason the writer believes his experience might be helpful to others confronted with the necessity of obtaining elevations single-handed. Others have had the same idea.

During 1941 and 1942, while in northwestern Indiana gathering well data for construction of a subsurface map, the writer traversed with plane table and telescopic alidade, using an automobile speedometer to measure distances.

In several trials over known distances it was found that measurements could be made with an error of 100 feet or less, usually no more than 50 feet. Reference to a stadia table shows that an error of 100 feet in the horizontal distance results in an error of about one foot in the difference of elevation, if the vertical angle is 34 minutes. From this it was decided that it should be possible to traverse along straight roads using the speedometer in place of stadia where the topography permitted the vertical angles to be kept under 30 minutes.

This idea was first tested by running a trial traverse over a 15-mile stretch of State highway in Jasper County, Indiana. Elevations at intersections along the route were obtained from the Indiana State Highway Department. These elevations were taken from the plotted centerline profile and should be accurate to the nearest $\frac{1}{2}$ foot.

A Stebinger table was calculated for the alidade and the vertical angles read to $\frac{1}{4}$ of a division (1/400 of a revolution). This is equivalent to an angle of about 5 seconds, representing, at a distance of 10,000 feet, a difference of elevation of approximately $\frac{1}{4}$ foot. In reading the speedometer, the tenths were divided into eighths.

Elevations were read on mailboxes, highway signs, a church steeple, et cetera. The largest angle read was $89\frac{1}{2}$ divisions of the Stebinger drum (approximately $0° 28'$). Several times it was possible to make a level sight to some part of the target. Two procedures were then available: (1) set the instrument up beside the target, measure the difference of elevation between the point sighted and the telescope, and read another foresight; (2) on the way to the next station stop and measure from the point sighted to the top of the target; then, on the backsight, read an angle to the top of the target. The second method is preferable because it keeps the foresights and backsights in better balance. Shots of 4,000 feet or more were corrected for curvature and refraction.

The instrument was set up 12 times in traversing the 15 miles. The length of

[1] Manuscript received, July 24, 1944.

[2] Gulf Refining Company.

the shots varied from 390 to 9,490 feet. The 390-foot shot was to get from a highway junction sign to the intersection at which the highway made a right-angle turn. A church steeple close to the road made the longest shot possible. A point may be on one side of the road by as much as 4 or 5 per cent of its distance from the instrument without significantly affecting the measured distance. If the measured distance is 10,000 feet and the target is 500 feet at right angles to the point measured to on the road, the error would be less than 15 feet. Consequently, the limiting factor usually is the ability to estimate the point at which an object is at right angles to the road.

Elevations were read on about half of the intersections along the way. The error of closure was 6 feet. Figure 1 shows the cumulative nature of the error.

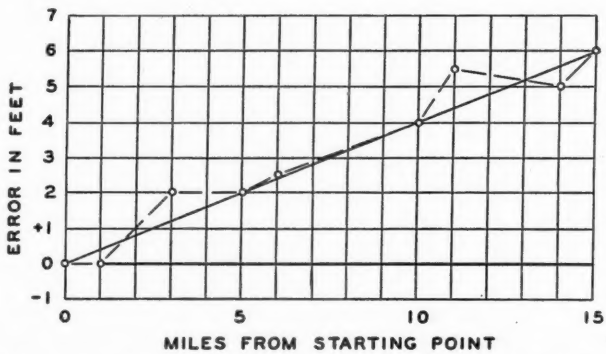

FIG. 1.—Distribution of errors on trial traverse. Circles indicate points at which traverse elevations were checked against highway elevations. Error (shown by dashed line) would be compensated by subtracting 6/15 or 0.4 foot times distance in miles from starting point. Correction is represented by solid line between zero on left and 6 on right. Thus, at 11 miles, 4.4 feet would be subtracted, leaving uncorrected error of +1.1 feet.

While it is possible, when weather conditions are ideal, to do as well with an altimeter, the error may all occur in one place, and thus a proportional correction may not improve matters very much. Furthermore, the plane table may be used when unstable atmospheric pressure makes an altimeter unreliable.

On the trial traverse the plane table was oriented at each set-up and the points were plotted to scale. Angles were read both with the Stebinger drum and on the vertical arc. On two different shots the vertical arc readings were identical (readings were made to $\frac{1}{2}$ minute). The corresponding Stebinger readings differed by $1\frac{1}{4}$ divisions, amounting to slightly more than a foot difference of elevation on a 10,000-foot shot. The 15-mile traverse was completed in about 6 hours. Heat waves frequently made it difficult to identify objects sighted on the longer shots.

Subsequently, in actually running well elevations, no map was used, the plane table being used solely for obtaining elevations. Angles were read only on the Stebinger drum, but were read twice and averaged, the telescope bubble being

reversed for the second reading. Heat waves were avoided as much as possible by doing the surveying either early or late in the day. In reading the speedometer, the tenths were at first subdivided into eighths, but later it was found just as easy to estimate tenths, which made it easier to reduce the readings to feet. If one had a great deal of this kind of work to do, the tenths dial on the speedometer could be divided into hundredths, by ruling fine lines on its face. Some years ago the writer saw a speedometer so marked in a car belonging to Professor H. W. Scott of Illinois University. Many have fastened counting devices to a wheel, and by this means distances could probably be measured as accurately in flat country as by stadia. Of course the speedometer used must be checked. The first car used on this project registered a mile while traveling 5,200 feet. Another car used later was found to travel 5,230 feet while registering one mile. It was also discovered that when the cars were backed up, the speedometers did not immediately reverse their direction. Consequently, if it is necessary to back the car to reach the starting point of a distance to be measured, it should be backed about 300 feet back of the point and brought up to it in a forward direction.

Care should be exercised to keep the tires inflated to the same pressure both when first checking the speedometer and whenever distances are to be measured. A tire soft enough to lower the axle $\frac{1}{8}$ inch does not appear low, but would cause the speedometer to record about 40 feet too much in a mile.

Since bench-marks are commonly set some distance from the road, a 4-foot length cut from a broken stadia rod came in handy for short stadia shots to get "into the clear." A 15-foot stadia rod was also used occasionally, when wells were beyond handlevel range of the road. The practice was to tie it to a fencepost or power pole along the road and in sight of the well. It was then "shot in" from a plane-table and speedometer traverse station, after which the site of the well was occupied and a backsight read.

Traverses were ordinarily limited to a few miles, the altimeter being used for wells far from bench-marks. For example, one well was located between two parallel State highways about 4 miles apart. Elevations had been obtained for the crossroads along both highways. Three set-ups were made in running a line along a connecting road passing about $\frac{1}{4}$ mile from the well. The instrument was first set up where this road intersected one of the highways, and a foresight read to a mailbox. The second set-up was on a low hill, from which a foresight was read to a warning sign at a jog in the road. The stadia rod was then tied to the signpost and a backsight read by stadia from the third set-up which was on a low hill about $\frac{1}{4}$ mile beyond. A foresight was then read on the stop sign where the road intersected the other highway. The difference of elevation between the stop sign and the center of the intersection was determined with a handlevel. The error of closure was about 2 feet. The 15-foot rod was tied to a fencepost along the road and "shot in" by stadia from a set-up beside the warning sign at the jog in the road. The 4-foot rod was stuck in the ground by the well casing. The plane table was then set up on intervening high ground and the job completed by stadia. This is typical of the use to which the method was put.

No attempt was made to discover how rough the topography might be without introducing significant errors into the measurement of distances. The writer did this work in an area which was, for the most part, very flat. It is probable that the same method could be used where the topography is rolling, provided one could take long enough sights to make it practical. Whether or not this method is applicable to any given project must be decided by balancing the accuracy required against the probable errors for the type of topography prevailing. It is thought that the 6-foot error on the trial traverse represents an extreme caused by a chance preponderance of positive values in errors which normally should be compensating.

CONCORD SALT DOME, ANDERSON COUNTY, TEXAS[1]

C. I. ALEXANDER[2]
Tyler, Texas

The Concord dome, Anderson County, was added to the list of proved interior salt domes of the East Texas basin by the Magnolia Petroleum Company's Henry Horowitz No. 1, which encountered salt at 6,002 feet and was abandoned, May 23, 1944, in salt at the total depth of 6,327 feet.

Prior to 1927 only six interior salt domes, Grand Saline in Van Zandt County, Steen and Brooks in Smith County, Keechi and Palestine in Anderson County, and Butler in Freestone County, were known in the East Texas basin.

The discovery of oil on the Boggy Creek dome, Anderson and Cherokee counties, in 1927, stimulated surface and geophysical exploration in this area resulting in the discovery of ten additional interior salt domes during the next 4 years. The last of this series of discoveries was the Mount Sylvan dome of Smith County, established as a salt dome area in 1931 by the Humble Oil and Refining Company's L. V. Reese No. A-1, which encountered anhydrite at 650 feet and salt at 1,050 feet, and was abandoned in salt at the total depth of 1,208 feet. No new salt-dome discoveries were made in the East Texas basin following this, until the presence of the Concord dome was established.

Surface and subsurface evidence indicate the probable presence of a salt dome near Marquez in Leon County, although the two wells drilled on the structure to date have not encountered any dome material.

The Concord dome is located in north-central Anderson County, 9 miles north and slightly west of Palestine, about 3 miles north and slightly east of the Keechi dome, and about 3 miles west and slightly south of the Brushy Creek dome.

The presence of a gravity anomaly led to exploration with reflection seismograph which indicated favorable structure. The first well on this structure, the Magnolia Petroleum Company's W. C. Campbell No. 1, J. B. McNeely Survey,

[1] Published by permission of the Magnolia Petroleum Company. Manuscript received, August 10, 1944.

[2] Magnolia Petroleum Company.

was completed on April 24, 1942, pumping 201 barrels of 12.2° gravity, black, asphalt-base oil per day from the Woodbine sand. Seven-inch casing was set in this well at 4,520 feet, with the drill hole plugged back to 4,540 feet. The top of the Woodbine was logged at 4,523 feet, and the total depth at 4,669 feet was in shale, containing a Washita microfauna. Subsequent wells drilled into the Washita limestone 40–50 feet below this point in the section.

The abnormally high structural position of this well, and the thin Woodbine, Eagle Ford, and Austin sections logged, suggested the possibility that the structure was a salt dome.

Three additional wells were drilled by the Magnolia Petroleum Company during 1942. All three were structurally 275–300 feet lower than the discovery producer on top of the Woodbine, and were dry and abandoned, after being drilled into the upper part of the Washita limestone. The second well on the structure, the Joel Kelley No. 1, J. B. McNeely Survey, was located about 1,600 feet southwest, the third, the H. E. Fitzgerald No. 1, J. N. Fitzgerald Survey, was 3,600 feet west and slightly north, and the fourth, the W. C. Campbell No. 2, J. B. McNeely Survey, was about 1,300 feet northeast of the W. C. Campbell No. 1.

In 1943 the Carter-Gragg Oil Company drilled Nannie Jarmillo No. 1, Elizabeth Groce Survey, a little less than 2 miles north of the Magnolia's Anderson No. 1, and logged the top of the Woodbine at 5,636 feet, 1,099 feet lower structurally than the discovery producer.

The Magnolia Petroleum Company's Horowitz No 1, located about 1,600 feet east and slightly north of the Campbell No. 1, was intended as a deep test for the structure. The top of the Woodbine was encountered at 4,982 (−4,352) feet, 429 feet lower than in the Campbell No. 1. The top of the Washita limestone was logged at 5,519 (−4,889) feet, and the well drilled from Washita limestone into salt at 6,002 feet. Salt penetration at this depth was indicated by a sudden decrease in the drilling-time rate, and by an increase in the viscosity and the salty taste of the drilling mud. A core from 6,069 to 6,079 feet recovered 10 feet of salt, and the well was drilled to the total depth of 6,327 feet in salt before being abandoned.

FOSSILS FROM LIMESTONE OF BUDA AGE IN DENTON COUNTY, TEXAS[1]

LLOYD W. STEPHENSON[2]
Washington, D. C.

In 1922 Robert T. Hill visited a locality in a north-south road cut in the south-facing slope of Denton Creek Valley, 4.8 miles east by north of Roanoke, Denton County, Texas. The results of his observations were published in the form of an

[1] Manuscript received, August 14, 1944. Published with the permission of the Director of the Geological Survey, United States Department of the Interior.

[2] Senior geologist, United States Geological Survey.

abstract in the *Proceedings* of the Thirty-Fifth Annual Meeting of the Geological Society of America, *Bulletin*, Vol. 34 (1923), pp. 72–73. Briefly, Dr. Hill observed at the top of the Grayson marl, the uppermost formation of the Comanche series in that area, a limestone which he correlated with the Buda limestone of Travis County, Texas. He mentioned the presence of characteristic Buda fossils but did not list them. He recognized a "distinct disconformity" between the Buda-like limestone and the overlying Woodbine formation (Dexter sand). He says,

> This paper gives additional proof of the stratigraphic correspondence between the Buda limestone of the Colorado River section of Texas and the Grayson and Main Street formations of north Texas. It likewise asserts that the Buda formation is not synchronous with the Woodbine formation of north Texas, as erroneously asserted by Böse and collaborators, but that the latter lies above the former with a stratigraphic and paleontologic disconformity between them.

In November, 1924, in company with William E. Wrather, the writer visited the Roanoke locality and collected a few fossils from the limestone. It appeared to them that Hill was correct in his correlation of the limestone and in his conclusion about the relation of the limestone to the Woodbine formation.

In May, 1944, in company with his assistant, Henry H. Gray, the writer revisited the locality and collected additional fossils from the limestone. The section as it was exposed in the road cut and ditches is described here.

Section Exposed in North-South Road on South-Facing Slope of Denton Creek Valley, 4.8 Miles East by North of Roanoke, Denton County, Texas

	Feet
Woodbine formation (Dexter sand)	
Fine sugary sandstone, more or less cross-bedded, with subordinate interbedded layers of gray clay	20
Light gray finely sandy clay with some thin layers of sand	10
Massive gray fine sandstone weathering reddish brown, mostly soft, but in part hard	15
Interbedded lenses of light gray argillaceous sand and sandy, shaly clay, in part ferruginous; vertical borings in upper one foot	8
Massive argillaceous sand	3
Fine sandstone, in part ferruginous, with interbedded gray shaly clay	2.5
Highly ferruginous, hematitic, nodular sandstone	0.5
Disconformity	
Grayson marl (?) (Buda-like facies)	
Light gray massive, earthy limestone with coarse irregular borings, 1–3 inches in diameter, extending downward from above to maximum depths of about one foot; these borings are filled with ferruginous sandstone like that immediately overlying the limestone; the limestone contains numerous fossils, mostly imperfectly preserved (see following list)	2–3
Gray massive marl, poorly exposed	20
Nodular fossiliferous limestone with interbedded gray marl; contains *Gryphaea mucronata* Gabb[1]	3
Concealed to level of bottom-land of Denton Creek, approximately	8
Total	93

[1] According to W. S. Adkins, in King, *Bull. Geol. Soc. America*, Vol. 50 (1939), p. 1669, the types of *Gryphaea mucronata* Gabb came from equivalents of the Fredericksburg group near Arivechi, Sonora, Mexico, and he suggests that the so-called *mucronata* so common in the Grayson marl should be given a new specific name.

A combined list of fossils collected on the two visits, from the Buda-like limestone forming the upper 2–3 feet of Grayson marl (?), follows.

FOSSILS FROM BUDA-LIKE LIMESTONE IN CUT OF NORTH-SOUTH ROAD, SOUTH-FACING SLOPE OF DENTON CREEK VALLEY, 4.8 MILES EAST BY NORTH OF ROANOKE, DENTON COUNTY, TEXAS. COMBINED LIST PREPARED FROM TWO COLLECTIONS, ONE MADE IN 1924 AND THE OTHER IN 1944

Echinodermata
Enallaster cf. *E. texanus* (Roemer). Identified by C. Wythe Cooke
Mollusca (Pelecypoda)
Inoceramus sp. (small fragments of a thick-shelled species)
**Exogyra clarki* Shattuck
Trigonia emoryi Conrad?
Pecten (*Neithea*), cf. *P.* (*N.*) *subalpina* Böse
**Pholadomya? roemeri* Shattuck
**Laternula? austinensis* (Shattuck)
**Homomya austinensis* Shattuck
Protocardia aff. *P. multistriata* Shumard
Mollusca (Gastropoda)
Tylostoma? sp.
Mollusca (Cephalopoda)
Turrilites cf. *T. brazoensis* Roemer
**Budaiceras* (2 species)

In addition to the species listed the collections include several unidentified pelecypods and gastropods.

So far as the records show, the species marked with an asterisk (*) are restricted in their vertical range to the Buda limestone. The other species in the list, none of which is positively identified, are of uncertain value in correlation. Some of them are long-ranging in the Comanche series.

The presence of four species of bivalve mollusks, that are restricted in their known range to the Buda limestone, and two species (probably undescribed) of *Budaiceras*, an ammonite genus known only from the Buda, is satisfactory evidence of the Buda age of the limestone in the section near Roanoke. If it is admitted that this limestone is a facies of Buda age in the upper part of the Grayson marl, then the Grayson is not the exact equivalent of the Del Rio but includes equivalents of both the Del Rio and the Buda.

If, on the other hand, the apparent absence of the Buda limestone at most places along the line of outcrop from Brazos River northward is due to its removal by post-Comanche erosion, leaving only a remnant of the limestone here and there, as that east of Roanoke, Adkins'[3] suppression of the name Del Rio, in favor of the earlier name Grayson, seems justified. The thickness of the Grayson marl in Denton Creek Valley east of Roanoke, according to Winton and Adkins,[4] is fully 75 feet, an amount nearly equalling that of the Del Rio clay (60–80 feet) farther south in Texas, where the Del Rio is overlain by the Buda limestone.

Which of the two alternatives mentioned is the correct one can not be confidently determined from the data now available. Change of facies from marl to limestone is theoretically easily possible, since the two kinds of rock differ from each other only in the relative proportions of clay and calcium carbonate composing them. It seems reasonable, therefore, that because of a temporary deficiency in the amount of transported clay, a limestone might be present, interbedded with a unit that is composed predominantly of marl.

[3] W. S. Adkins, "Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), pp. 386–400.

[4] W. M. Winton and W. S. Adkins, "The Geology of Tarrant County," *Univ. Texas Bull. 1931* (1919), p. 73.

The other alternative, namely, that the absence of the Buda limestone is due to removal by erosion, derives some support from the fact that the Grayson marl becomes thinner from Denton Creek Valley northward. Nowhere in Grayson County does the thickness equal half of that measured in the Roanoke section. The maximum measured thickness of the marl in Grayson County is about 28 feet and adjacent to the Preston anticline in a section on Sandy Creek near Cedar Mills, first reported by Fred M. Bullard,[5] and recently examined by Roy T. Hazzard, B. W. Blanpied, W. C. Spooner, Henry H. Gray, and the writer, the marl is locally completely cut out by erosion, allowing the Dexter sand to rest directly on the Main Street limestone.

Regardless of the correct relationship of the Grayson marl to the Del Rio clay and the Buda limestone, the presence east of Roanoke of a limestone containing a Buda fauna, disconformably overlain by the Dexter sand, demonstrates that the Dexter is not a sand facies of the Buda limestone, as has been advocated by Böse and others.

[5] Fred M. Bullard, "The Geology of Grayson County, Texas," *Univ. Texas Bull. 3125* (1931), pp. 48–51.

FULLERTON POOL, ANDREWS COUNTY, TEXAS[1]

J. H. MOORE[2]
Hobbs, New Mexico

Discovery of oil from the Clear Fork group, lower Permian age, in the Fullerton field marked the first important discovery of oil from this zone in the North-Central Basin Platform area of West Texas. The discovery well, Fullerton Oil Company's Wilson No. 1, was completed, March 3, 1942, with an initial potential of 680 barrels of oil per day. Later wells were completed with potentials in excess of 2,000 barrels of oil per day, indicating a field of major importance. The discovery well is located in Sec. 15, Block A-32, P.S.L. Survey, in northwest Andrews County, Texas, approximately 15 miles northwest of the town of Andrews, Texas, and 25 miles southeast of Hobbs, New Mexico. To date, 16,000 acres have been proved by out-stepping wells. The limits of production have been partly defined on the west, southwest, and east, forming the present outline of production as 4 miles wide from east to west and 7 miles long from north to south.

The structural features of the field, as revealed by drilling thus far, indicate a broad "high" extending north and south, with local closures of different strike on the "high." An elongate northeast-southwest closure, centering in Secs. 16 and 17, Block A-32, has been defined and reversals of dip have been indicated in wells both north and south of the first closure to give the impression of other closures. There is 350 feet of relief between the structurally highest wells and edge wells where the top of the producing interval is near the water level.

Formations penetrated are normal for the Central Basin Platform area and include the following strata. Approximately 70–100 feet of surface sands and caliche overlie about 1,800 feet of redbeds, including the Dockum group of the Triassic

[1] Manuscript received, August 17, 1944.

[2] Geologist, Fullerton Oil Company.

and the uppermost Permian. Two hundred feet of Rustler anhydrite overlies the Salado salt, which is approximately 1,200 feet thick. Under the salt is 1,500 feet of anhydrite, sand, and dolomite in the Whitehorse group, which includes the Tansill, Yates sand, Seven Rivers, and Grayburg formations. The San Andres group, below the Whitehorse group, is approximately 1,600 feet thick. The upper 1,200 feet consists mainly of anhydritic dolomite with streaks of black shale and small amounts of chert. The lower 400 feet is the San Angelo formation which is anhydritic dolomite with stringers of coarse-grained gray sand. There is scattered porosity with oil-staining in the upper 600 feet of the San Andres. This interval has been tested in several wells, but oil has not been produced in commercial quantities.

The Clear Fork group is 1,000–1,200 feet thick and its top is 6,100–6,200 feet from the surface. The upper 400 feet of Clear Fork is anhydritic dolomite with partings of black shale. Below this interval is a sand and dolomite member approximately 50 feet thick. This sandy interval is fairly consistent over the field and its top can be used as a contour datum to reflect the structure of the producing zone. This sandy member is commonly called either the "Tubb" sand, because of a comparable occurrence in the Sand Hills (Tubb) field, Crane County, Texas, or the "Fullerton" sand.

The producing interval occurs 250 feet below the top of the sand member and is 350–400 feet thick in the structurally highest wells. The interval consists of tan and buff crystalline dolomite with streaks of tan and gray limestone near the middle and bottom of the zone. There are inclusions of anhydrite and streaks of black shale throughout the producing interval, varying in amount from well to well, depending on structural position. The occurrence of limestone also varies considerably over the field. Most of the porosity occurs in the crystalline dolomite. In some wells the limestone contains excellent sucrose and cavernous porosity.

Development in the field has been rapid. On August 1, 1944, there were 82 completed wells, all flowing except one pumper, and 45 drilling rigs in operation. The oil produced is 41°–43° gravity sweet oil, which is a desirable crude for both gasoline and lubricating-oil stock. The wells are completed with gas-oil ratios of 600–1,200 cubic feet per barrel. The original bottom-hole pressures were 2,950–3,000 pounds per square inch.

At present a south out-stepping well, the Mid-Continent Petroleum Company's University No. 1–7, located in Sec. 20, Block 13, 5 miles south of the Fullerton discovery well, is being drilled below the regular Fullerton producing zone. A deeper producing interval has been indicated at the depth of 8,470–8,750 feet. This interval of coarsely crystalline white dolomite has been identified by some as Devonian, comparable with the porous intervals described by T. S. Jones.[3] The Mid-Continent's deep test is the first well in the immediate vicinity of the Fullerton field drilled below the Permian.

[3] T. S. Jones, "Dolomite Porosity in Devonian of West Texas Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 7 (July, 1944), p. 1043.

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RESEARCH NOTES

RESEARCH PROGRAM[1]

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Now is an appropriate time to reappraise the research effort in the field of petroleum geology. Doubtless, all will agree that:

(1) To discover and develop, in the United States, new reserves of about 2,000,000,000 barrels annually as now needed will call for exhaustive and extensive scientific study;

(2) Future discoveries will commonly require application of more scientific skill than in the past;

(3) Many technical advances of recent years should be further perfected and brought into general use;

(4) New approaches and new methods of finding oil should be developed;

(5) Time for post-war planning is at hand and research projects, particularly those of a fundamental nature, should be formulated as soon and as definitely as possible;

(6) A well-rounded, balanced program of research should be organized and set in motion.

Nearly all geological work is of a research nature, either routine or fundamental. Company geologists and individuals are chiefly engaged in the search for new data and the application of known methods. Broad fundamental studies can be undertaken in most cases only through coöperative effort. Such effort in the past has been largely under the auspices and financial support of the American Petroleum Institute. Project 43, "Transformation of organic matter into petroleum and identification of source beds," is the only geological investigation now being financed by the American Petroleum Institute. The annual appropriation of $23,360 for this project is less than one-fifth of the total research budget of the Institute. Many other important fields of fundamental research related to petroleum geology should be receiving attention but inaction is likely to continue unless worthy, concrete projects are outlined and energetically advocated.

At a recent meeting of the Association's executive committee, the research committee was urged to undertake the development of a broad research program in petroleum geology by any means the committee may see fit to employ. The research committee in turn solicits coöperation from all members of the Association in this endeavor. Some individuals will, no doubt, be able to propose definite projects, while others as in the past will be able to formulate, carry to completion, and publish in the *Bulletin* or elsewhere the results of their own research work. All may participate in advising our representatives in government that efficient production rates and adequate supply of this essential commodity require the discovery and development of much larger reserves than have obtained during recent years. The uses of petroleum and its products are so essential, and the task of finding and developing 2,000,000,000 barrels annually is so great that liberal appropriations should be made for governmental agencies doing research work in this field.

During the past 3 months the writer has conferred with at least 300 members of the Association regarding proper policy for the Association to follow in furthering the research effort. Opinion is practically unanimous that major research projects might well be formu-

[1] Manuscript received, September 20, 1944.

[2] Chairman, research committee.

lated and sponsored by the Association and its research committee, but that the Association should not compete with other organizations in attempting to raise and administer large sums of money for financing these projects. The possible sources of sizable funds—government, company, institutional, and individual—are perhaps greater than we realize, but it is quite certain that these funds will not come out of hiding unless and until well thought out, attractive, definite research projects in petroleum geology are developed and recommended by individuals or societies qualified to speak with authority. In the field of petroleum geology our Association is certainly eminently qualified to speak with authority.

The coöperation of each member of the Association is requested in developing definite research projects as well as a broad plan of attack. More coördination of research effort by the Association and its affiliated societies might bring important results, particularly by stimulating local research groups which may generate new and deserving research projects. Appointment of a committee on research by each affiliated society appears desirable. Where possible a resident member of the Association research committee might serve as chairman of the local committee. All members of the local committees would be urged to attend the annual business meeting and conferences of the Association research committee. A conference on research projects and ways and means of securing greater research effort and better liaison between the Association and affiliated societies is being planned for the next annual meeting of the Association.

Many research ideas should spring from the members of the local groups and the research committee, but these ideas will have to be taken out of the conversational stage into the project stage by outlining in detail plans for doing the necessary research work. Each project should have as its goal the increasing of our oil-finding and producing efficiency. After examining many ideas critically and developing a certain number of worthy, well organized research projects, we should know better than we now know what should be done in the field of research in petroleum geology and, furthermore, should be in a position to attract sizable funds to the support of further research.

The petroleum industry has successfully met tremendous demands imposed by war conditions. The critical part played by petroleum in national welfare and security has been well demonstrated and widely recognized. This is a propitious time to plan and set in motion a greatly expanded research program in the field of petroleum geology. Suggestions and coöperation of the Association's entire membership and others are urgently requested.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

FOREIGN MAPS, BY E. C. OLSON AND AGNES WHITMARSH

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

Foreign Maps, by E. C. Olson and Agnes Whitmarsh. Harper's Geoscience Series (1944). 231 and xv pp. including preface, author's introduction, table of contents, list of illustrations, and index. Harper and Brothers, New York, N. Y. Price, $4.00.

During World War II some of the members of the American Association of Petroleum Geologists are learning to use foreign maps the hard way. After the war is over many more members will need to know how to read and interpret foreign maps, for then American enterprise will be reaching out for additional oil fields to supplement the rapidly dwindling supplies on the North American continent. Such geologists will be grateful to Olson and Whitmarsh for their eminently useful book.

This book is the natural outgrowth of courses given by the senior author at the University of Chicago and special classes in map reading given by him in the Institute of Military Studies. The difficulties which arise in locating maps and later in using them effectively are analyzed. Furthermore, practical methods of solving the difficulties so encountered are presented. The data are presented in simple form, yet they are complete, practical, and emphasized by maximum utility.

In the first chapter the characteristic maps of the United States are fully described. Although geologists are fairly well acquainted with such maps, they will find in this chapter many details which are valuable and which they did not know before. Five classes of maps are very fully described. They are the U. S. topographic maps, the U. S. Army Corps of Engineers maps, the maps of the alluvial valley of the Mississippi, the maps of the Tennessee Valley Authority, and the planimetric maps of Louisiana, Wisconsin, and Michigan. Special details that geologists will be interested in are the nature of the U. S. rectangular grid system described on page 6 and the Harriman system described on page 10.

In Chapter II the authors analyze the problems of interpreting foreign maps under the following headings: (1) language, (2) signs and symbols, (3) grid systems, (4) measurements and scales, (5) index systems. In addition, they devote considerable space to political problems and to special problems connected with the nature of an area. The third chapter is entirely devoted to the information which appears on the margins of maps. Such details as title of map or series, map scale, coverage of map, dates of publication, agent of publication, elevation and relief, magnetic declination, symbols, and grid systems are taken up and examined in a general way.

Map indexes and types of map indexes are extremely valuable in locating the particular map one has need for. In Chapter IV the authors describe the geographic index and the Harriman index rather fully and devote considerable space to the index systems which are independent of standard grids. The availability of index sheets and also their preparation are covered adequately.

The problem of language is taken up in Chapter V. Inasmuch as this problem looms as the greatest and the most formidable, the way it is handled by the authors will bring a sigh of relief to the reader. What might be considered an insurmountable obstacle in the path of the wandering geologist proves to be merely a low hurdle. The authors show that only

[1] University of Wichita. Manuscript received, August 7, 1944.

six languages are extensively used on maps—the Roman, Arabic, Greek, Cyrillic (Russian), Chinese, and Japanese. Pages 52 to 135 are devoted to glossaries in which all the common terms used on such maps are presented. The terms are arranged in alphabetical order beginning with the Annamese, followed by the Arabic and ending with the Turkish language. These glossaries are not exhaustive, but do include all common map terms and will probably serve the necessary purpose of any geologist even though he may be entirely unfamiliar with the language involved on the map. The languages used in the principal parts of the world are listed and enumerated in Chapter VI. Here also the reader will find beautifully illustrated type maps of 16 different countries printed in full collotype reproduction and in many cases in color.

The signs and symbols used on foreign maps are fully described in Chapter VII. The standard or conventional symbols are described first, then the methods of representing relief, and finally the use of colors. In Chapter VIII the important matter of scales and measurement is taken up. A table on page 169 gives the local units of measurement used by the various nations. The nature of the grid system which is of supreme importance in some areas is treated at length in Chapter IX. Under the geographic systems help is presented in working out problems in conversion of longitude. Under the heading of rectangular grids there is a very full discussion which is arranged according to nations. Chapter X is a very valuable part of the book. It lists the agencies (by nations) which issue maps. For those who wish to do further reading on the subject of maps a carefully selected list of books and articles is given in the appendix pages 223 to 230.

In conclusion, the reviewer wishes to state that the authors of *Foreign Maps* have done a unique service for the geologist who must leave the familiar maps of the United States and search for oil on foreign lands. For such a geologist the book is absolutely indispensable.

RECENT PUBLICATIONS

ALASKA

*"Oil Seepages on the Alaskan Arctic Slope," by Norman Ebbley, Jr. *Mining and Metallurgy*, Vol. 25, No. 453 (New York, September, 1944), pp. 415–19; 5 photographs, 1 map.

BRAZIL

*"Bibliografia e Indice da Geologia do Brasil, 1641–1940," by Dolores Iglesias. *Brasil Div. Geol. e Min. Bol. 111* (1943). 323 pp. Departamento Nacional da Producao Mineral, Rio de Janeiro, D. F., Brasil, S. A.

APPALACHIANS

"Oil and Gas Possibilities of the First Berea Sand in Southeastern Ohio and Western West Virginia," by J. F. Pepper *et al. U. S. Geol. Survey Prelim. Map 9*, Oil and Gas Investig. Ser. (August, 1944). For sale by Director, Geological Survey, Washington (25), D. C. Price, $0.50.

CALIFORNIA

*"The Geology and Paleontology of the Marine Pliocene of San Diego, California, Part 1, Geology," by Leo George Hertlein and U. S. Grant, IV. *Memoirs San Diego Soc. Nat. Hist.*, Vol. 2 (August 30, 1944). 72 pp., 6 text figs., 18 pls., 1 physiographic block diagram. 9×11.5 inches. Paper cover. May be obtained from Director, Natural History Museum, Balboa Park, San Diego, California. Price, $1.50, postpaid.

*"Check List of California Tertiary Marine Mollusca," by A. Myra Keen and Herdis Bentson. *Geol. Soc. America Spec. Paper 56* (New York, August 30, 1944). 280 pp., 4 figs., 2 tables.

"Map of Del Valle Oil Field, California," by J. C. Miller and Ruth Lebow. Shows areal geology, subsurface structure contours and 3 stratigraphic, structure sections. Not published. In open files of the Conservation Branch of the U. S. Geol. Survey, Room 533, Post Office and Court House Building, Los Angeles, for inspection by anyone interested in the field.

CANADA

*"Canadian Oil Search Turns to New Areas," by H. G. Cochrane. *World Petroleum,* Vol. 15, No. 9 (New York, August, 1944), pp. 30–33; 7 photographs, 1 map.

COLORADO

*"Morrison Formation and Related Deposits in and Adjacent to the Colorado Plateau," by William Lee Stokes. *Bull. Geol. Soc. America,* Vol. 55, No. 8 (New York, August, 1944), pp. 951–92; 5 pls., 5 figs.

ENGLAND

*"Stratigraphy and Structures East of Oxford. Part II: The Miltons and Haseleys," by William Joscelyn Arkell. *Quar. Jour. Geol. Soc. London,* Vol. 100, Nos. 397–98 (July 28, 1944), pp. 45–60; 5 figs., 1 pl. (areal geology in colors).

*"Stratigraphy and Structures East of Oxford, Part III: Islip," *ibid.*, pp. 61–73; 7 figs., 1 pl. (geological map).

FLORIDA

"The Molluscan Fauna of the Alum Bluff Group of Florida," by Julia Gardner. Part VII, "Stenoglossa" (in part). *U. S. Geol. Survey Prof. Paper 142 G* (July, 1944), pp. 437–91, Pls. 49–51. Sold by Supt. Documents, Govt. Printing Office, Washington 25, D. C. Price, $0.25.

GENERAL

*"Correlation of the Cambrian Formations of North America," by Cambrian Subcommittee, B. F. Howell, Chairman. *Bull. Geol. Soc. America,* Vol. 55, No. 8 (New York, August, 1944), pp. 993–1004; 1 pl.

*"Correlation of the Cretaceous Formations of the Greater Antilles, Central America, and Mexico," by Ralph W. Imlay. *Ibid.*, pp. 1005–46; 3 pls., 1 fig.

*"Notes on the Compressibility of Clays," by Alec Westley Skempton. *Quar. Jour. Geol. Soc. London,* Vol. 100, Nos. 397–98 (July 28, 1944), pp. 119–35; 11 figs.

*"The Compaction of Muddy Sediments," by Owen Thomas Jones. *Ibid.*, pp. 137–60; 1 fig.

GULF COAST

"Correlation of Lower Cretaceous Formations of the Coastal Plain of Texas, Louisiana, and Arkansas," *U. S. Geol. Survey Prelim. Chart 3,* Oil and Gas Investig. Ser. (August, 1944). For sale by Director, Geological Survey, Washington (25), D. C. Price, $0.50.

ILLINOIS

"Symposium on Devonian Stratigraphy." *Illinois Geol. Survey Bull. 68-A* (Urbana, 1944), pp. 89–222, Figs. 14–53. *Gratis.* Postage, 4¢.

"An Annotated Synopsis of Paleozoic Fossil Spores and the Definition of Generic Groups," by J. M. Schopf, L. R. Wilson, and Ray Bentall. *Illinois Geol. Survey Rept. Inv. 91* (Urbana, 1944). 72 pp., 3 pls., 5 figs. Price, $0.25. Postage, 4¢.

"Progress Reports on Subsurface Studies of the Pennsylvanian System in the Illinois Basin." *Ibid., Rept. Inv. 93.* 87 pp., 12 figs., 5 pls. Price, $0.25. Postage, 4¢.

"Corals from the Chouteau and Related Formations of the Mississippi Valley Region," by William H. Easton. *Ibid., Rept. Inv. 97.* 93 pp., 17 pls., 1 fig. Price, $0.25. Postage, 4¢.

*"The Structure Diorama" (Lawrence County, Illinois), by Frederick Squires. *Oil and Gas Jour.*, Vol. 43, No. 15 (Tulsa, August 19, 1944), pp. 86–93; 6 figs.

*"Factors Controlling Oil-Well Completions in the Illinois Basin," by Carl A. Bays. *Ibid.*, Vol. 43, No. 18 (September 9, 1944), pp. 49–57; 6 figs.

"Oil and Gas Development in Illinois in 1943," by A. H. Bell and C. W. Carter. *Illinois Geol. Survey Illinois Petroleum 50* (Urbana, 1944). 110 pp. Postage, 3¢.

KANSAS

*"East Kansas Water Flooding," by Frank B. Taylor. *Oil Weekly*, Vol. 115, No. 2 (Houston, September 11, 1944), pp. 17–20; map and photograph.

KENYA

*"The Miocene Beds of Kavirondo, Kenya (Africa)," By Percy Edward Kent. *Quar. Jour. Geol. Soc. London*, Vol. 100, Nos. 397–98 (July 28, 1944), pp. 85–118; 8 text figs., 4 photographs.

MISSISSIPPI

*"Geology and Ground-Water Resources of the Camp Shelby Area," by Glen Francis Brown, in coöperation with the United States Geological Survey and the Mobile United States Engineer Office. *Mississippi Geol. Survey Bull. 58* (University, 1944). 72 pp., 8 figs., 7 pls., 9 tables.

NEW MEXICO

*"Stratigraphy of the Colorado Group, Upper Cretaceous, in Northern New Mexico," by Charles H. Rankin, *New Mexico Bur. Mines and Min. Resources Bull. 20* (Socorro, 1944). 30 pp., 6 figs. Price, $0.25.

"Oil Possibilities in Upper Pecos River and Rio Galisteo Region, New Mexico," by C. B. Read and D. A. Andrews. *U. S. Geol. Survey Prelim. Map 8*, Oil and Gas Investig. Ser. (August, 1944). For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.30.

OKLAHOMA

*"Significant Features of West Edmond Field," by E. G. Dahlgren. *World Petroleum*, Vol. 15, No. 9 (New York, August, 1944), pp. 40–41; 3 photographs, 1 cross section.

*"West Edmond Field Presents Paradox," by Charles J. Deegan. *Oil and Gas Jour.*, Vol. 43, No. 18 (Tulsa, September 9, 1944), pp. 45–47; 2 maps, cross section, key map, and production chart.

*"West Edmond Opens Big Area for Hunton," by E. G. Dahlgren. *Oil Weekly*, Vol. 115, No. 3 (September 18, 1944), pp. 30–34; 3 figs.

RUSSIA

*"Sakhalin Island Has Good Possibilities," by Don L. Carroll. *Oil Weekly*, Vol. 114, No. 13 (Houston, August 28, 1944), pp. 28–30, sketch map.

WALES

*"The Ordovician Rocks of Arvon," by Edward Greenly. *Quar. Jour. Geol. Soc. London*, Vol. 100, Nos. 397–98 (July 28, 1944), pp. 75–83; 4 figs.

WESTERN INTERIOR

"Thickness and General Character of the Cretaceous Deposits in the Western Interior of the United States," by John B. Reeside, Jr. *U. S. Geol. Survey Prelim. Map 10*, Oil and Gas Investig. Ser. (August, 1944). For sale by Director, Geological Survey, Washington (25), D. C. Price. $0.25.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 18, No. 5 (September, 1944).

"The Cephalopod Fauna of the Pennsylvanian Union Valley Formation of Oklahoma," by A. K. Miller and John Britts Owen.

"Cretaceous, Tertiary, and Recent Corals, a Sponge, and an Alga from Venezuela," by John W. Wells.

"Ostracoda from the Reklaw Eocene of Bastrop County, Texas," by Morton B. Stephenson.

"Permian Trilobites from Western Australia," by Curt Teichert.

"A New Paleocene Gastropod from Southern California," by Robert R. Compton.

"The Auditory Region in Some Miocene Carnivores," by Margaret Jean Hough.

SOUTH LOUISIANA DEEP-SEATED DOMES

The paper entitled "South Louisiana Deep-Seated Domes" by W. E. Wallace, Jr., appearing in the September number of the *Bulletin*, may be recommended to all students of faulting. It contains a wealth of factual information regarding the faulting associated with those domes; and since the information is based primarily on electric logs, it may be regarded as relatively precise.

It is interesting to note that Wallace finds more than one type of normal fault as a result of these detailed studies. His findings in that respect lend support to the idea that our knowledge of the subject has reached the stage where a genetic classification of faults is now practicable.

STUART K. CLARK

CONTINENTAL OIL COMPANY
PONCA CITY, OKLAHOMA
September 20, 1944

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 10 (OCTOBER, 1944), PP. 1550-1552

THE ASSOCIATION ROUND TABLE

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CONSTITUTION AND BY-LAWS

CORRECTION—ANNUAL DUES

Corrections should be made in the by-laws as printed on page 1408 of the September *Bulletin*, Vol. 28, No. 9. ARTICLE I, DUES, SECTION 2, first paragraph, 3rd, 4th, and 5th sentences, should read as follows.

> The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before *December* first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by *January* first shall not receive copies of the *January Bulletin* or succeeding *Bulletins*, nor shall they be privileged to buy Association special publications at prices made to the membership, until such arrears are met.

The foregoing is in accordance with official action of the Association in annual meeting at Dallas, Texas, March 23, 1944.

1945 DUES

Dues statements for 1945 are being mailed in November, 1944, in conformity of the amendments to the by-laws passed at the last annual meeting. Members are reminded to pay dues promptly. Early payment in November and December will give greater assurance of prompt receipt of the January *Bulletin*—which cannot be sent until 1945 dues are paid.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 10 (OCTOBER, 1944), PP. 1553-1556, 1 FIG.

Memorial

CHARLES BREWER, JR.

(1900–1944)

Charles Brewer, Jr., died on the morning of January 2, 1944, after a short illness of influenza and pneumonia.

Charles was born in Falmouth, Massachusetts, on August 22, 1900. His grammar-school education was completed at Brown and Nichols School, Cambridge, Massachusetts, in 1918, at which time he enlisted in the United States Army Air Force and attained the rank of 2nd Lieutenant before being honorably discharged at the cessation of hostilities in 1919.

In the fall of 1919 he entered Harvard College, and in his second year in this institution his interest in geology grew. He graduated from Harvard in 1923 with A.B. degree in geology. He entered the University of Pittsburgh Graduate School in 1925 and received his Master of Science in petroleum geology in 1927.

With his academic studies completed, Charles spent the next 4 years in the West, his first employer being the United States Geological Survey, making plane-table surveys in Wyoming. From 1928 to 1931 he was employed as field geologist by the Indian Territory Illuminating Oil Company, Bartlesville, Oklahoma.

In 1931 he returned east and was employed as temporary geologist at the New York State Museum, Albany, New York, and in this capacity he compiled a report on Allegany State Park, New York, published under the title, "Oil and Gas Resources of Allegany State Park." At this time he also taught in the Allegany School of Natural History.

From 1931 to 1935 he was associated with Torrey, Fralich and Simmons, geologists, Bradford, Pennsylvania. In 1935 he became geologist for Godfrey L. Cabot, Inc., New York division, and in the same year he was transferred to the West Virginia division, Charleston, West Virginia, as chief geologist, and had been elevated to the position of assistant general superintendent about 6 months prior to his death.

He was one of the charter members of the Appalachian Geological Society; he was secretary-treasurer in 1938–1939, vice-president in 1940–1941, and president in 1942–1943.

He leaves his wife, Patricia Moncrieff Brewer, and one son, Charles Brewer III, aged 4.

To those who knew him and worked with him, he was an inspiration and a wise counsellor. It is deeply regrettable that such a promise of a wonderful future ended so suddenly.

His ashes were scattered upon the Atlantic Ocean, near his boyhood home, with the reading of Tennyson's "Crossing the Bar," by his father.

> "And may there be no moaning of the bar,
> When I put out to sea."

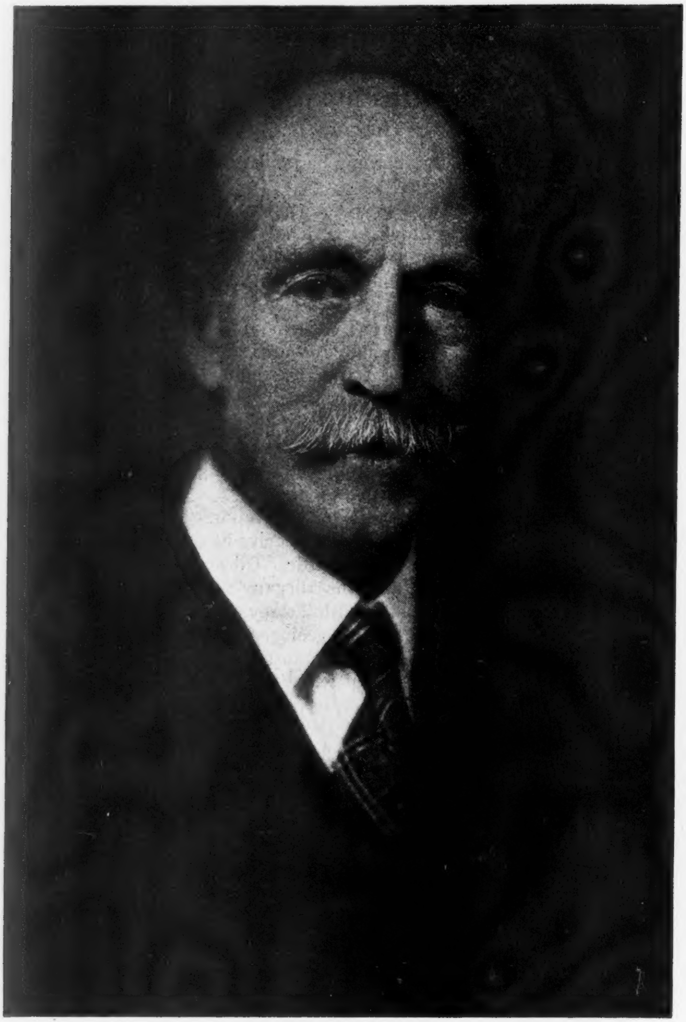
H. J. Simmons, Jr.

Charleston, West Virginia
August 7, 1944

ARTHUR KEITH

(1864–1944)

American geology owes much to Arthur Keith whose professional career covered a span of nearly 60 years devoted to frontier problems in a growing field of science. His contributions to geologic knowledge lay principally in his areal mapping and structural inter-



Photograph by Bachrach

ARTHUR KEITH

pretation of the ancient mountain-built terranes of eastern North America. So sound were his conclusions that in time both national and international recognition came to him.

Arthur Keith was born in St. Louis, Missouri, on September 30, 1864; shortly thereafter his family established its home in Quincy, Massachusetts. There Keith's education began in the public schools and continued in Adams Academy. In due course he entered

Harvard College from which he graduated in 1885. He remained for 2 years at Harvard to study under Nathaniel Southgate Shaler in Lawrence Scientific School. His scientific career may be said to have commenced at that time, for in the following year he served as a member of the Massachusetts Topographic Survey. He was appointed a member of the United States Geological Survey in 1887, and began the extensive mapping of the southern Appalachians. From 1907 to 1913 he was placed in charge of the Division of Areal and Structural Geology of the United States Geological Survey and for 8 years following was in charge of such work in the United States east of the Rocky Mountains. For the last decade before his official retirement in 1934 he returned to active field work in the northern Appalachian region included in New England and eastern Canada. His studies were primarily structural but included investigations of the St. Lawrence earthquake of 1925 and the Grand Banks earthquake of 1928.

Following his retirement from the United States Geological Survey, he continued his structural and stratigraphic investigations, principally in the Gaspé region of Quebec Province.

Among the special tasks which he was called on to perform were studies for the United States Army, during World War I, of the geographic features of military significance in the New England border and of suitable limestone areas for furnishing high-grade limestone to the nitrogen-fixing plant at Muscle Shoals, Alabama. He served as professor in the department of geology, University of Texas, in 1926. In 1933 he was called in as a geologic consultant to the Tennessee Valley Authority in connection with the location of the Norris Dam.

Keith was married on June 29, 1916, to Elizabeth Marye Smith of Athens, Ohio. The union bore no children. Mrs. Keith died in January, 1942.

He was a member and fellow of various professional organizations and served in official capacities in many of them. Most notable among these offices may be listed: president, the Geological Society of America, 1927; chairman, Division of Geology and Geography, National Research Council, 1928–1931; treasurer, National Academy of Sciences, 1932–1940; president, Geological Society of Washington, 1914. His service on committees of professional organizations was very extensive.

Although Arthur Keith had no direct professional connection with petroleum geology he was a most conscientious member of the American Association of Petroleum Geologists and closely followed its meetings and publications. It is difficult to assess the values that Keith derived from the Association and those that the Association derived from Keith. There is little doubt that both benefited tremendously.

In the 1880's and 1890's the emphasis placed on the reporting of observations and field data through the medium of the United States Geological Survey folios was a trend in American geology which coincided with Keith's talents and inclinations. The numerous folios from the southern Appalachians prepared by him attest the vigor with which he pursued his duties.

Those were the pioneer days of accurate geologic mapping. Those were pioneer days also in transportation and hostelry in the southern Appalachians. Keith travelled by team and buck-board where roads permitted, beyond that by horseback and on foot. Overnight accommodations, when weather necessitated, were not infrequently cabin lean-tos where chickens roosted in the rafters close overhead. Under difficult field conditions precise instrumental surveys were scarcely practicable. As a result Keith developed a facile yet highly accurate mapping technique which required the minimum of dunnage. He used enlarged maps on which he plotted his observations in the field, entering a prodigious amount of data in microscopic lettering using his own code of abbreviations. Observations were made on pace-and-compass traverses between control points which were established by transit or alidade. This method lent itself peculiarly well to the regional interpretation

of structural and stratigraphic data and permitted extensive areal documentation for his portrayal of the spectacular folded and faulted overthrusts which were novelties at the time they were disclosed.

In its broader aspects Keith's life and work may be regarded as representative of those individuals whose energy and conscientious effort in the generation following the establishment of the Geological Survey built the foundations for the professional prestige which that institution enjoys. His saga is definitely an element of the saga of American geology, a bright thread in the warp and woof of the fabric of our science.

Allyn C. Swinnerton
Major, Signal Corps

On Leave from Antioch College
Yellow Springs, Ohio
August 18, 1944

DAVID H. GRAHAM

(1910–1944)

His untimely death on August 30, 1944, terminated the career of a young geologist of outstanding ability and delightful personality—David H. Graham.

Mr. Graham was born on December 27, 1910, in Chicago, Illinois. He attended the University of California at Los Angeles, where he received the A.B. degree in 1934 and M.A. degree in 1936, both in geology.

He began his professional work with the Union Oil Company in 1936 and in 1938 joined the geological staff of E. I. du Pont de Nemours and Company. Although his work with that company did not deal with petroleum geology, he kept up his interest in that field. His professional experience, following his year in field geology with the Union Oil Company, included geological mapping of ilmenite deposits in California and in Espirito Santo, Brazil, in which country he spent a year. He was then assistant manager in the development of a fluorspar mine at Arrey, New Mexico.

In addition to his membership in the A.A.P.G., he was a member of Sigma Gamma Epsilon and an associate member of Sigma Xi. He was also a junior member of the American Institute of Mining and Metallurgical Engineers. Besides his interest in geology, he had an extensive knowledge of astronomy and had served as a lecturer in the Griffith Observatory in Los Angeles, conducting popular lectures in the planetarium. He had a remarkable ability of making astronomy interesting to children.

He is survived by his widow, Mrs. Dorothy B. Graham, and a daughter, Patricia Frances, aged one year. His death was caused by Bright's disease.

J. L. Gillson

Wilmington, Delaware
September 19, 1944

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 10 (OCTOBER, 1944) PP. 1557-1560

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CARLETON D. SPEED, JR., who has been in charge of the exploration section of the production division of the Petroleum Administration for War for the past 2 years, has resigned.

WILLIAM H. ATKINSON presented a paper on the West Edmond oil pool at a meeting of the Oklahoma City Geological Society, September 7.

GEORGE GAENSLEN, formerly with the Amerada Petroleum Corporation at Midland, Texas, is in the employ of the Standard Oil Company of Egypt, Cairo, Egypt.

FRED MADERA, recently with the Ohio Oil Company, is now with the Fullerton Oil Company at Hobbs, New Mexico.

P. L. DANA has left the Gulf Oil Corporation to joint the J. M. Huber Corporation, Borger, Texas.

DALE H. ROWDEN, geologist, has resigned as appraisal agent for the Republic National Bank of Dallas to become a consultant.

DON D. MONTGOMERY, superintendent for the Murphy Land Company, El Dorado, Arkansas, in 1942, has been promoted to be a captain in the Quartermaster Corps.

RUFUS M. SMITH, who has been geologist for the Panhandle Eastern Pipe Line Company for several years at Kansas City, Missouri, is a lieutenant in the United States Naval Reserve.

JOHN VAN DALL has resigned as district geologist for the Magnolia Petroleum Company at Oklahoma City, to manage the stripper well properties of G. I. and W. E. Van Dall, Bartlesville, Oklahoma. WALTER L. MOREMAN succeeds Van Dall for the Magnolia at Oklahoma City.

MERYL D. WILLIAMS, formerly with University Lands, is employed by the Seaboard Oil Company at Midland, Texas.

HARRY H. POWER has returned to resume his duties as chairman and professor in the department of petroleum engineering at the University of Texas, after a summer's work as consultant to the production research department of the Humble Oil and Refining Company, Houston, Texas.

L. T. CLARK is employed in the Oklahoma City office of the Sohio Petroleum Company, as junior geologist.

RUSSELL H. DICKEN is with the Republic Oil Company, First National Bank Building, Miami (32), Florida.

VIRGIL E. COTTINGHAM is petroleum engineer and chairman of the North Basin Pools Engineering Committee, Box 1851, Midland, Texas.

B. G. MARTIN is with the Gulf Oil Corporation at Fort Worth, Texas.

MAISIE I. COON, West Texas Geological Society Merit Award honoree, is in the geological department of the Humble Oil and Refining Company, Box 2180, Houston (1), Texas.

PARK J. JONES, recently with The Texas Company, is now a production consultant Box 6622, Houston (5), Texas.

Major C. W. COUSER, formerly with the Carter Oil Company, has moved from Arlington, Virginia, to Cedar Rapids, Iowa.

THOMAS J. NEWBILL, JR., is in the employ of the Standard Oil Company of California, at the following address: Apartado Nacional 2760, Bogota, Colombia, S. A.

EUGENE C. REED is associate State geologist, University of Nebraska, Lincoln, Nebraska.

JAMES WELDON THOMAS, recently with Geophysical Service, Inc., Houston, Texas, is with Petroleos Mexicanos, Depto. de Exploracion, Av. Juarez 95, Mexico, D. F.

LEROY T. PATTON of Texas Technological College, Lubbock, Texas, has been professor of geology and petroleum engineering since 1925. He is head of the department.

RUSSELL C. COOPER, formerly acting district geologist in the Evansville district, has now been made district geologist in charge of Evansville district for the Sinclair Wyoming Oil Company. His territory covers Illinois, Indiana, and Kentucky.

R. L. MCLAREN has resigned his position as head of the geophysical department of the Arkansas Natural Company, Shreveport, Louisiana. He is general manager of the Texas Seismograph Company, Wichita Falls, Texas.

W. E. BELT, JR., has resigned from the United States Geological Survey and has accepted the position of geologist with the Southern Natural Gas Company, at Jackson, Mississippi.

DONALD M. REESE is with the Atlas Oil and Refining Corporation of Shreveport, Louisiana. His address is Box 1447, Jackson, Mississippi.

H. C. DAVIS, formerly with The Texas Company, is now with the Vickers Petroleum Company, Wichita, Kansas.

JOHN MAN MORGAN, formerly with the Union Producing Company, Houston, Texas is with the Superior Oil Company, Jackson, Mississippi.

DAVID M. WEBER has left the Mene Grande Oil Company, Barcelona, Venezuela, and is now with the Gulf Research and Development Company, Laurel, Mississippi.

S. G. WAGGONER, first lieutenant in the Army, was retired to civilian status in August and has opened an office in the First National Bank Building, Wichita Falls, Texas, where he will do private and consulting work in petroleum geology.

DONALD W. GRAVELL has left the Atlantic Refining Company of Cuba to go with the Venezuelan Atlantic Refining Company, Caracas, Venezuela.

B. B. BRADISH, of the Carter Oil Company, Woodward, Oklahoma, has been commissioned in the United States Naval Reserve as a lieutenant, junior grade, DV-(S), and has left for active duty.

NORMAN HARDY, vice-president and general manager of the Standard Oil Company of California, San Francisco, is also a director of the company.

WILLIAM H. CARTER, assistant geologist of the Magnolia Petroleum Company, at Midland, Texas, has accepted a commission in the United States Naval Reserve and is now on active duty. His address is Ensign William H. Carter, Camp MacDonough, Plattsburg, New York.

F. E. MARSHALL has left the Snowden & McSweeney Company. He is with the Alder Oil Company, Fort Worth, Texas.

W. MELVIN STIRTZ has resigned his position with the Cities Service Company, Bartles-

ville, Oklahoma, and is now connected with the Kerlyn Oil Company in Shreveport, Louisiana.

D. HAROLD CARDWELL, of the Sun Oil Company, has been transferred from Tyler, to become district geologist at Midland, Texas.

J. BOYD BEST is with the Ohio Oil Company, San Antonio, Texas.

J. HARLAN JOHNSON, associate professor at the Colorado School of Mines, Golden, has returned after 4 months of field work in northern Mexico.

Major EDGAR W. OWEN, former persident of the Association, has been in the Pacific region for many months. He is in the Army Air Corps, handling aerial photographs. He writes that he finds geologists in all sorts of places where their special training is of real significance. Unofficially and modestly he places geologists next to doctors and experienced construction engineers as being the most valuable professional men who have come within the scope of his war experience.

HORACE G. RICHARDS is associate curator, department of geology and paleontology, of the Academy of Natural Sciences of Philadelphia.

W. J. HENDY, JR., is with the Magnolia Petroleum Company. His address is Box 1249, Meridian, Mississippi.

B. W. COLLINS gave an illustrated lecture on "An Oil Geologist in New Guinea," on June 26, before the Auckland Institute, a branch of the Royal Society of New Zealand. At present Collins is engaged in essential-industry work in chemistry for the Dominion Compressed Yeast Company in Auckland. His petroleum exploration experience includes New Guinea and New Zealand.

Lieutenant Commander J. S. HEROLD, formerly with the Forest Development Company, Midland, Texas, writes that he has participated in two invasions in the European area and three in the Pacific Ocean theater.

ROBERT L. GEYER, recently with the Shell Oil Company, Inc., is in the employ of the Rohr Aircraft Company, Chula Vista, California.

M. E. STUMP, formerly with the Sunray Oil Company, at Tulsa, is now with the British-American Oil Company Limited, at Calgary, Alberta, Canada.

The Houston Geological Society held its first regular fall meeting on the mezzanine floor of the Texas State Hotel at noon, September 21. Following the luncheon, OLIN D. BELL talked on "Operational Work of Photo Reconnaissance and Photo Mapping Squadrons." Colonel Bell recently returned from duty at Peterson Field, Colorado Springs.

HERBERT INSLEY, senior petrographer of the United States Bureau of Standards, has been appointed professor of petrography and head of the department of earth sciences at the Pennsylvania State College.

Election of officers was held by the Indiana-Kentucky Geological Society at a meeting, at Evansville, Indiana, July 26. They are as follows: president, ROBERT F. EBERLE, Superior Oil Company; vice-president, STANLEY G. ELDER, Sun Oil Company; secretary-treasurer, HILLARD W. BODKIN, Superior Oil Company.

OSCAR M. HUDSON, formerly with the Midstates Oil Corporation, is district geologist for the Phillips Petroleum Company at Evansville, Indiana.

EDWIN D. MCKEE has moved from the Museum of Northern Arizona, at Flagstaff, to the department of geology of the University of Arizona, at Tucson.

WALLACE W. HAGAN, recently with the Indiana State Division of Geology at In-

dianapolis, is in the Employ of the Tide Water Associated Oil Company, Tulsa, Oklahoma.

W. C. CLARK, formerly with the Continental Oil Company at Ponca City, Oklahoma, is with the British-American Oil Producing Company, Casper, Wyoming.

WARD C. BEAN, of the Shell Oil Company, Inc., formerly at Wichita Falls, Texas, is now at Tulsa, Oklahoma.

LINN M. FARISH was killed in action in the Balkans, September 11, according to an Associated Press report. Major Farish was in the employ of several oil-producing companies in the United States from 1927 to 1941, before joining the Civilian Technical Corps and going to England.

V. E. MONNETT, director of the schools of geology and geological engineering at the University of Oklahoma, has been named dean of the graduate college for a period of 2 years by the University board of regents. He is thus ex-officio director, temporarily of the University of Oklahoma Research Institute. Monnett has been a member of the University faculty since 1917.

DISTINGUISHED LECTURE TOURS

The 1944–45 season of distinguished lectures before the affiliated societies under the sponsorship of the A.A.P.G. distinguished lecture committee has opened with the tours of two field geologists of the United States Geological Survey. These men have been active in the Survey's program of investigations designed to foster an increase in petroleum reserves, and they discuss the progress in their particular fields of investigation.

Charles B. Read reported on the stratigraphic and structural studies of the Survey in northern New Mexico. He outlined the conclusions which have been reached and the problems still unsolved under the lecture title "Geology and Upper Paleozoic Stratigraphy in Portions of Northeastern New Mexico" before the following societies.

September	29	Rocky Mountain Association of Petroleum Geologists at Denver
October	2	Noon—Tulsa Geological Society at Bartlesville
		Evening—Tulsa Geological Society at Tulsa
	3	Kansas Geological Society at Wichita
	4	Oklahoma City Geological Society at Oklahoma City
	5	Fort Worth Geological Society at Forth Worth
	6	North Texas Geological Society at Wichita Falls
	9	West Texas Geological Society at Midland
	10	Texas Technological College at Lubbock
	11	Panhandle Geological Society at Amarillo

Watson H. Monroe, who has spent the last 15 years in investigations of the Coastal Plain sediments east of the Mississippi River, recently completed the field studies and office consultations which have resulted in the new geologic map of Mississippi. This important contribution to geological information has been followed by studies of the Eutaw and Tuscaloosa formations which are still in progress. Monroe discusses the stratigraphic problems involved in these investigations before the following societies under the title "The New Geologic Map of Mississippi and Related Problems."

October	13	Mississippi Geological Society at Jackson
	16	Shreveport Geological Society at Shreveport
	17	Dallas Petroleum Geologists at Dallas
	18	Houston Geological Society at Houston
	19	South Texas Geological Society at San Antonio
	20	Corpus Christi Geological Society at Corpus Christi
	23	South Louisiana Geological Society at Lake Charles
	24	New Orleans Geological Society at New Orleans
	26	Southeastern Geological Society at Tallahassee

JOHN L. FERGUSON, *chairman*

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - Ben H. Parker
Colorado School of Mines, and Frontier Refining Company
1st Vice-President - - - - - - Dart Wantland
Colorado School of Mines
2nd Vice-President - - - - Wm. B. Kramer
U. S. Geological Survey
Secretary-Treasurer - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - - Robert F. Eberle
The Superior Oil Company

Vice-President - - - - - - - Stanley G. Elder
Sun Oil Company

Secretary-Treasurer - - - - Hillard W. Bodkin
The Superior Oil Company

Meetings will be announced.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - H. C. Petersen
Freeport Sulphur Co., American Bank Bldg.
Vice-President and Program Chm. - - - -
- - - - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Secretary-Treasurer - - - - - B. E. Bremer
The Texas Company, P.O. Box 252

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - - C. B. Roach
Shell Oil Company, Inc., Box 136
Vice-President - - - - - - - P. S. Shoeneck
Atlantic Refining Company
Secretary - - - - - - - - - Ben F. Morgan
Stanolind Oil and Gas Company
Treasurer - - - - - - - . Robert N. Watson
Atlantic Refining Company, Box 895

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Fred H. Moore
Magnolia Petroleum Co., Box 535, Mt. Vernon

Vice-President - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Secretary-Treasurer - - - - Everett F. Stratton
Schlumberger Well Surveying Corporation, Box 491, Mattoon

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - - Leo R. Fortier
Alpine Oil and Royalty Co.
Vice-President - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Secretary-Treasurer - - - - Delbert J. Costa
Superior Oil Co. of California
417 First Natl. Bank Bldg.
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Bldg.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President . - - - - - - - R. M. Wilson
Ohio Oil Company, Drawer 1129, Zone 91
Vice-President - - - - - - - - E. P. Ogier
c/o W. C. Spooner, Box 1195, Zone 90
Secretary-Treasurer - - - - - L. H. Meltzer
Union Producing Co., Box 1407, Zone 92

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - Edward J. Baltrusaitis
Gulf Refining Company, Box 811, Saginaw
Vice-President - - - - - Raymond S. Hunt
Consulting, 405 S. Main, Mt. Pleasant
Secretary-Treasurer - - - - Thomas S. Knapp
The Chartiers Oil Co., Box 227, Mt. Pleasant
Business Manager - - - - - - Lee S. Miller
Michigan Geological Survey,
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - L. R. McFarland
Magnolia Petroleum Company

Vice-President - - - - - - - - J. B. Storey
Union Producing Company

Secretary-Treasurer - - - - Frederic F. Mellen
British-American Oil Producing Company
1007 Tower Building

Meetings: First and third Wednesdays of each month from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - John Marshall
The Texas Company, Box 539

Vice-President - - - - - - Frank Neighbor
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - - - S. L. Rose
618 Simpson Building

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - E. G. Dahlgren
Interstate Oil Compact Commission
State Capitol

Vice-President - - - - - Theodore G. Glass
Sinclair Prairie Oil Company
703 Colcord Building

Secretary-Treasurer - - - - - C. E. Hamilton
Consolidated Gas Utilities Corporation
814 Braniff Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday, at 12:00 noon, Y.W.C.A. Cafeteria.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - Roy D. McAninch
Stanolind Oil and Gas Company, Box 1099

Vice-President - - - - - - - - E. R. Owen
Phillips Petroleum Company, Box 152

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - J. V. Howell
1506 Philtower

1st Vice-President - - - - - - - W. H. Butt
Atlantic Refining Company

2nd Vice-President - - - - W. Reese Dillard
Consulting

Secretary-Treasurer - - - - - - - - L. C. Case
Gulf Oil Corporation, Box 661

Editor - - - - - - - - - - - Roy L. Ginter
U. S. Geological Survey

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - - Ira H. Stein
Continental Oil Company, 604 Driscoll Building

Vice-President - - - - - Henry D. McCallum
Humble Oil and Refining Company

Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 904 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - Joseph M. Wilson
Continental Building

Vice-President - - - - - - Henry C. Cortes
Magnolia Petroleum Company

Secretary-Treasurer - - - - H. C. Vanderpool
Seaboard Oil Company

Executive Committee - - - - Cecil H. Green
Geophysical Service, Inc.

Meetings: Regular luncheons, first Monday of each month, 12:00 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - G. J. Loetterle
Shell Oil Company, Inc., Box 2037

Secretary-Treasurer - - - - - L. L. Harden
Sinclair Prairie Oil Company, Box 1110

Executive Committee - - - - J. H. McGuirt
Magnolia Petroleum Company

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - Joseph H. Markley, Jr.
The Texas Company, Box 1720

Vice-President - - - - - - James L. Morris
The Pure Oil Company, Box 2107

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - - - Leslie Bowling
Union Oil Company of California

Vice-President - - - - - W. B. Milton, Jr.
Gulf Oil Corporation

Secretary - - - - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Treasurer - - - - - - - - - G. J. Smith
Pan American Producing Company

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - Donald Kelly
The Texas Company

Vice-President - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Secretary-Treasurer - - - David T. Richards
Shell Oil Co., Inc., Box 2010

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO, TEXAS

President - - - - - - - Robert N. Kolm
Atlantic Refining Co., 1742 Milam Building

Vice-President - - - - - Donald O. Chapell
Transwestern Oil Co., 1600 Milam Building

Secretary-Treasurer - - - Robert D. Mebane
Saltmount Oil Co., 916 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - Robert I. Dickey
Forest Development Corporation

Vice-President - - - - - George R. Gibson
Richfield Oil Corporation

Secretary-Treasurer - - - - - - Jane Ferrell
Magnolia Petroleum Company, Box 633

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - - Veleair C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - - Charles E. Stout
United Fuel Gas Company, Box 1273

Editor - - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas

Vice-President - - - - - - Henry C. Cortes
Magnolia Petroleum Company, Dallas, Texas

Editor - - - - - - - - - Joseph A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - W. Harlan Taylor
Petty Geophysical Engineering Company
1449 Esperson Bldg., Houston, Texas

Past-President - - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

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P.O. Box 410, El Dorado, Arkansas


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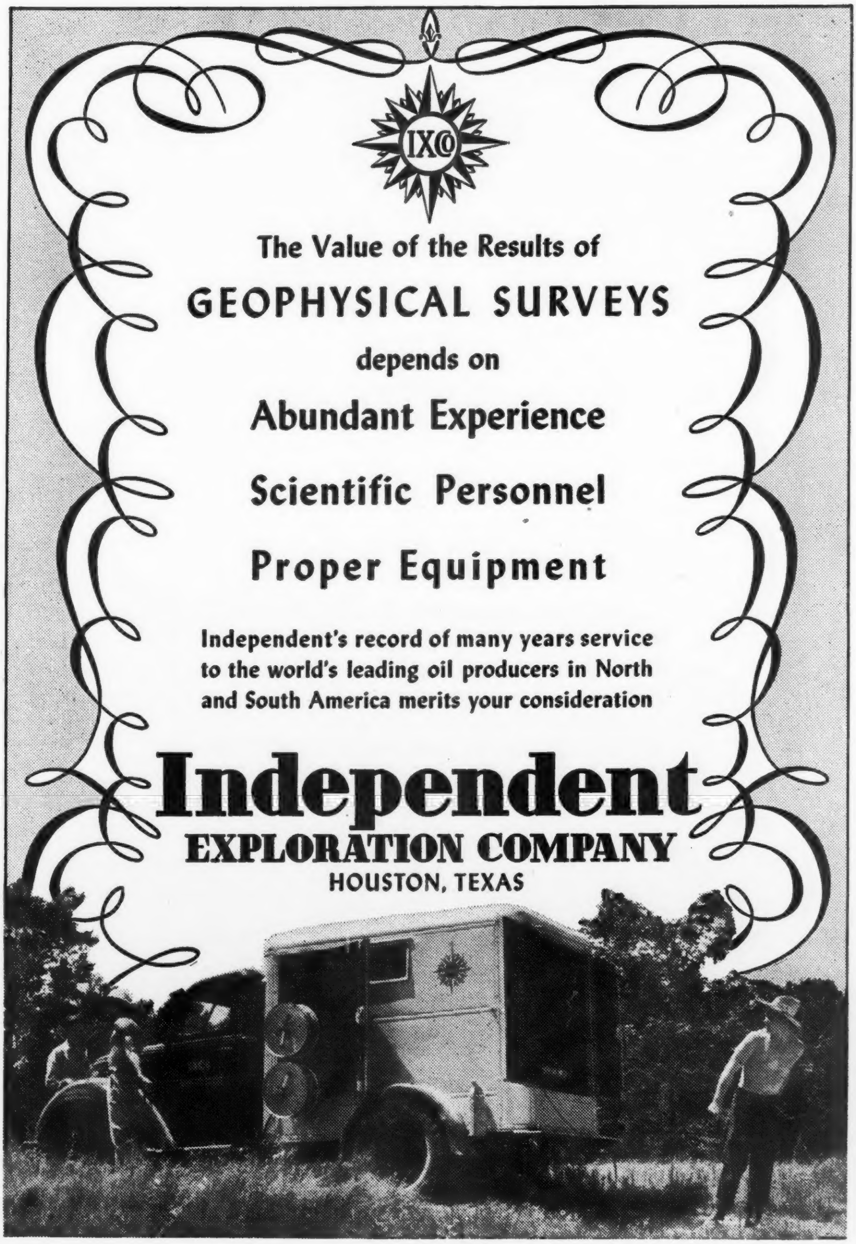
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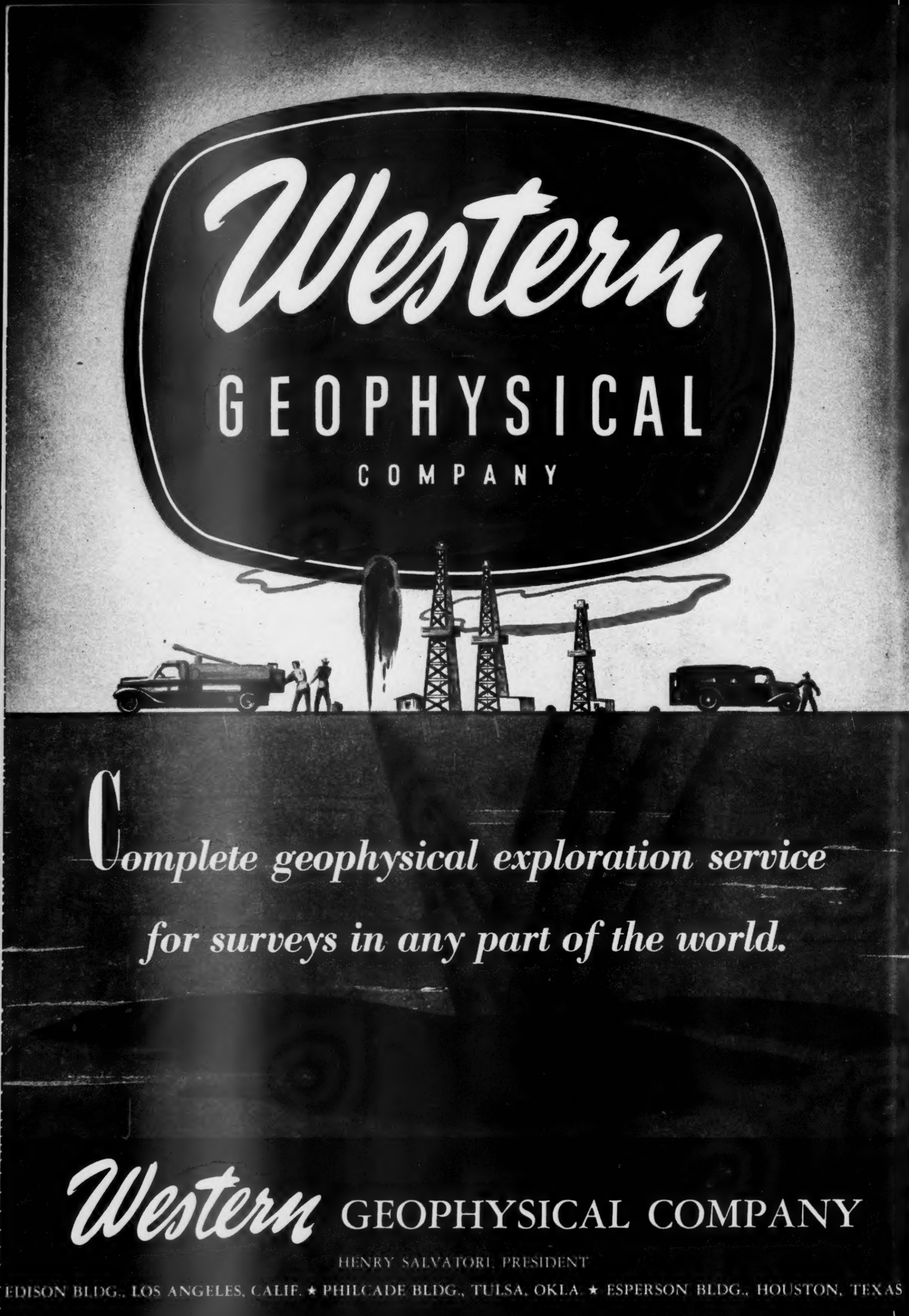
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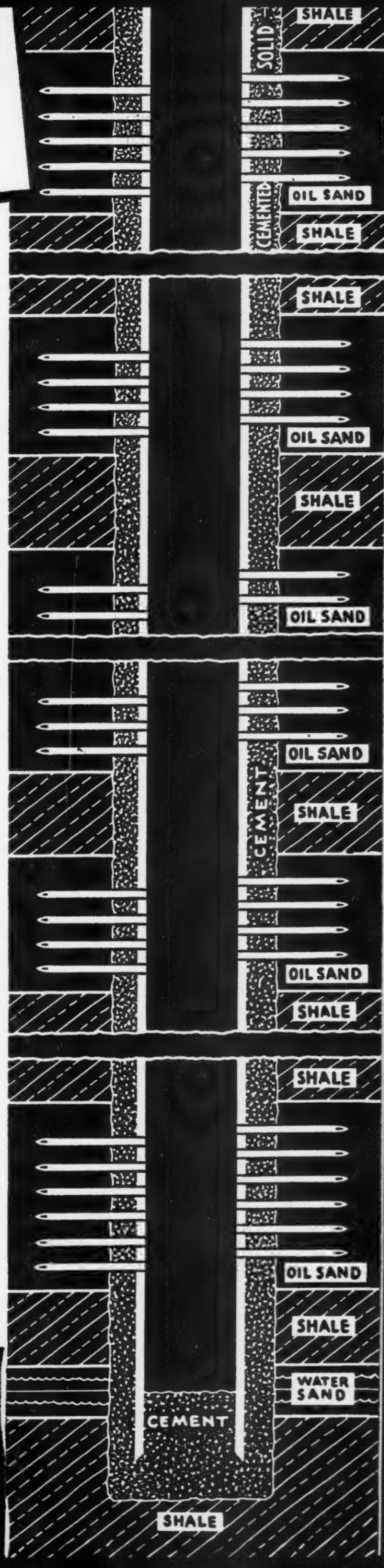

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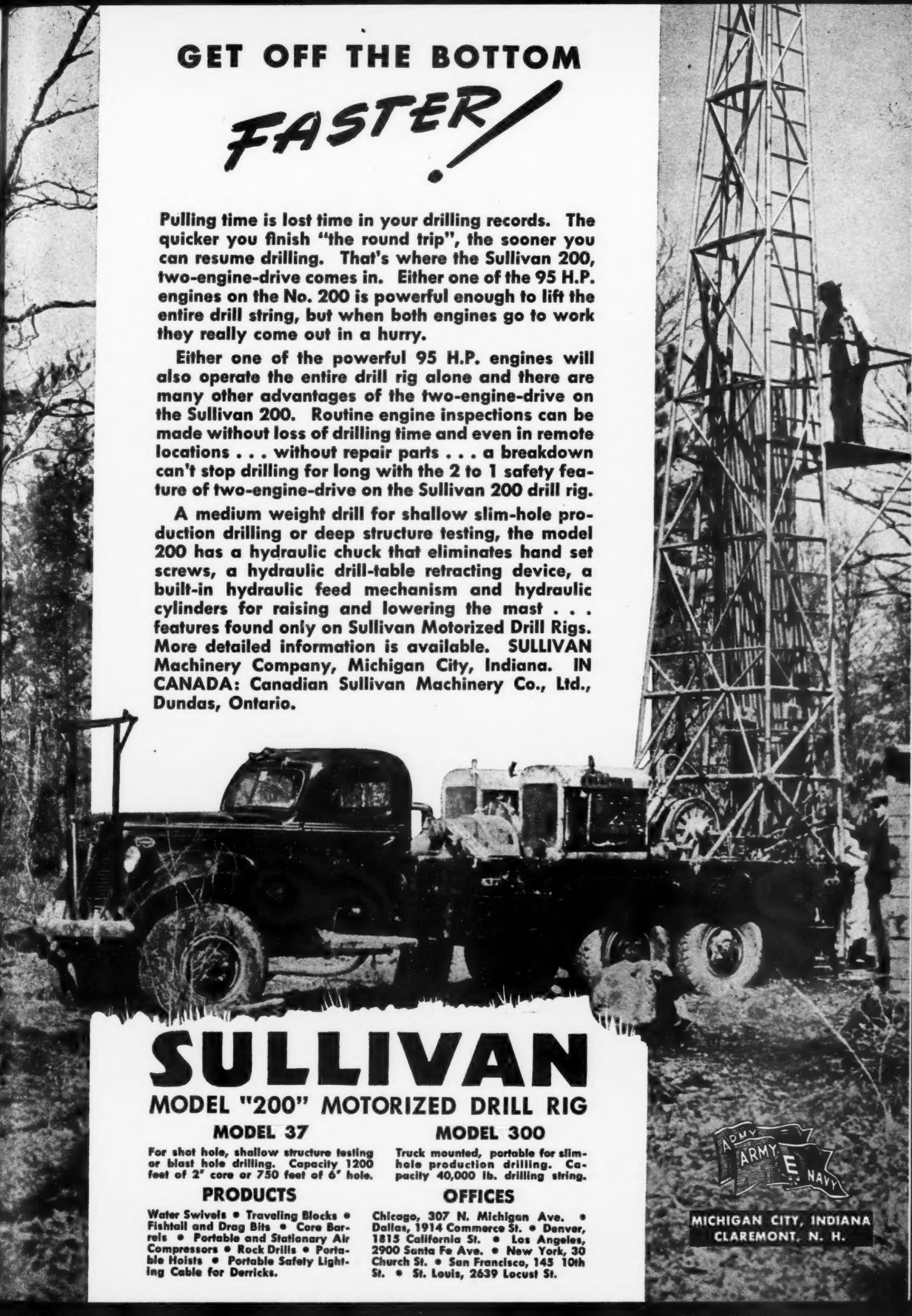
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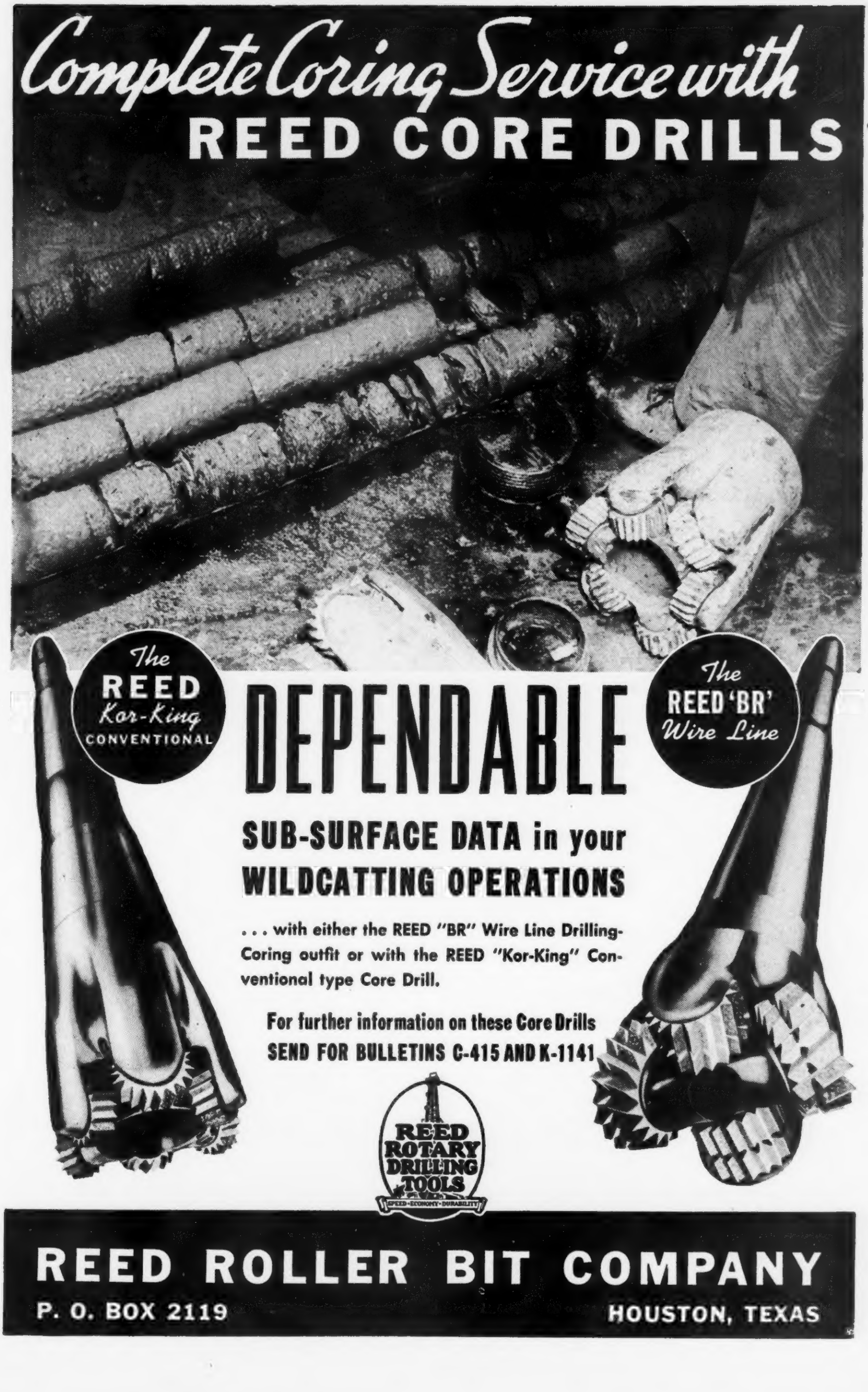
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